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TECHNICAL REPORT

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AIRCRAFT NOISE EVALUATION

SEPTEMBER 1968

DEPARTMENT OF TRANSPORTATION

FEDERAL AVIATION ADMINISTRATION

Office of Noise Abatement

Washington D.C. 20590

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WILLIAM C. SPERRY

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FEDERAL AVIATION ADMINISTRATION
OFFICE OF NOISE ABATEMENT
Technical Support Staff
Washington, D. C.

ABSTRACT

The Federal Aviation Administration, in response to Public Law 90-411, has begun the rulemaking process leading to the certification of aircraft for noise. The basic element in the regulation criteria is the noise evaluation measure designated as effective perceived noise level, EPNL, which is a single number evaluator of the subjective effects of aircraft noise on human beings. Simply stated, EPNL consists of instantaneous perceived noise level corrected for tones and duration. The history of the development of EPNL is presented and a critical evaluation of its validity is made. The computational procedures are described in detail including both integration and approximate methods for calculating duration corrections. Examples are given in the appendices.

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Symbol	Unit	Description
ant	-	Antilogrithm to the Base 10.
C	dB	Tone Correction. The factor to be added to PNL to account for the presence of discrete frequencies.
d	sec	Duration Time. The length of the significant noise time history; it is the time interval between the limits of t(1) and t(2).
D	dB	Duration Correction. The factor to be added to PNLM to account for the time history of the noise.
EPNL	dB (1)	Effective Perceived Noise Level. The value of PNL adjusted for both the presence of discrete frequencies and the time history.
f(i)	Hz	Frequency. The geometrical mean frequency in the i-th one-third octave band.
F(i)	dB	Delta-dB. The difference between the original and background sound pressure levels in the i-th one-third octave band.
h	dB	dB-Down. The level to be subtracted from PNLM which defines the significant noise time history.
(i)	-	Frequency Band Index. The numerical indicator which denotes any one of the 24 one-third octave bands from 50 to 10,000 Hz.
(k)	-	Time Increment Index. The numerical indicator which denotes the number of equal time increments that have elapsed from a reference zero.
log	-	Logarithm to the Base 10.
log n(0)	-	Noy Discontinuity Coordinate. The log n value of the intersection point of the straight lines representing the variation of SPL with log n.
M(1) M(2)	-	Noy Inverse Slope. The reciprocals of the slopes of the straight lines representing the variation of SPL with log n.

(1) It is common practice to use the designation EPNdB for the unit of effective perceived noise level instead of dB.

Symbol	Unit	Description
n(i)	noy	Perceived Noisiness. The perceived noisiness at a given instant of time that occurs in the i-th one-third octave band.
n	noy	Maximum Perceived Noisiness. The maximum value of all of the 24 values of n(i) that occurs at a given instant of time.
N	noy	Total Perceived Noisiness. The total perceived noisiness at any given instant of time calculated from the 24-instantaneous values of n(i).
OASPL	dB	Overall Sound Pressure Level. The sound pressure level that occurs at a given instant of time over all of the 24 one-third octave bands from 50 to 10,000 Hz.
p(1) p(2)	- -	Noy Slope. The slopes of the straight lines representing the variation of SPL with log n.
PNL(k)	dB (2)	Perceived Noise Level. The perceived noise level at the k-th increment of time calculated from the 24-instantaneous values of SPL(i).
PNLM	dB (2)	Maximum Perceived Noise Level. The maximum value of PNL(k) which occurs during the aircraft flyover.
PNLP	dB (2)	Peak Perceived Noise Level. The perceived noise level computed from the highest levels reached in each of the one-third octave bands irrespective of time. It is commonly referred to as composite perceived noise level.
PNLT(k)	dB (2)	Tone Corrected Perceived Noise Level. The value of PNL adjusted for the presence of discrete frequencies that occurs at the k-th increment of time.
PNLTM	dB (2)	Maximum Tone Corrected Perceived Noise Level. The maximum value of PNLT(k) which occurs during the aircraft flyover.
s(i)	dB	Slope of Sound Pressure Level. The change in level between adjacent one-third octave band pressure levels at the i-th band.

(2) It is common practice to use the designation PNdB for the unit of perceived noise level instead of dB.

Symbol	Unit	Description
$\Delta s(i)$	dB	Change in Slope of Sound Pressure Level.
$s'(i)$	dB	Adjusted Slope of Sound Pressure Level. The change in level between adjacent adjusted one-third octave band sound pressure levels at the i-th band.
$\bar{s}(i)$	dB	Average Slope of Sound Pressure Level.
SPL(0)	dB	Noy Discontinuity Coordinate. The SPL value of the intersection point of the straight lines representing the variation of SPL with log n.
SPL(1) SPL(2)	dB dB	Noy Intercept. The intercepts on the SPL-axis of the straight lines representing the variation of SPL with log n.
SPL(i)	dB	Sound Pressure Level. The sound pressure level at a given instant of time that occurs in the i-th one-third octave band.
SPL'(i)	dB	Adjusted Sound Pressure Level. The first approximation to background level in the i-th one-third octave band.
SPL"(i)	dB	Background Sound Pressure Level. The final approximation to background level in the i-th one-third octave band.
t	sec	Flyover Time. The length of time measured from a reference zero that has elapsed during the aircraft flyover time history.
t(1) t(2)	sec	Time Limit. The beginning and end of the significant noise time history defined by h.
Δt	sec	Time Increment. The equal increments of time for which PNLT(k) are calculated.
T	sec	Normalizing Time Constant. The length of time used as a reference in the integration method for computing duration corrections.

1. INTRODUCTION

The aircraft noise legislation recently passed by the 90th Congress, Reference 1, delegates to the Federal Aviation Administration the authority and responsibility to certificate aircraft for noise. The rule-making process will consist of a number of formal steps beginning with a notice of proposed rule-making (NPRM) and ending with issuance of a noise certification regulation. During each of the steps, the general public and the aviation community (airport, airline, and aircraft operators and aircraft manufacturers) will be solicited for their inputs in order to arrive at the most equitable noise regulation. The public must be sufficiently protected from the noise environment so that it will be neither harmful not unnecessarily annoying and the aviation community must be permitted to function in a reasonably efficient manner.

Initially, the regulation will not be ideal because compromises will have to be made. The public will be subjected to more annoyance and the aviation community will operate less efficiently than each would prefer. However, in order to reflect the results of experience and research advancements, the regulations will be revised periodically with the objective of maintaining maximum equity and to insure that the improved state-of-the-art of noise abatement is translated into engine/aircraft design at the earliest practical date. The noise regulatory process, with the understanding and cooperation of the public and the aviation community, can be an effective mechanism for aiding the orderly growth of the aviation industry. It is conceivable that aircraft noise exposure ultimately can be confined to areas and controlled to levels acceptable to all concerned.

The formal process of noise certification has begun for the FAA only since the regulation authority has been granted. However, in anticipation of this, considerable informal effort has been devoted, for the past three years, to aircraft noise evaluation, measurement, and criteria as related to certification. Reference 2 clearly indicated to the aviation community that aircraft noise regulation authority was being sought by the FAA. The work of Woodall and his scientific advisors, Reference 3, yielded six informal documents on the criteria and technology being considered by the FAA. References 4, 5, and 6 emphasized and extended the Woodall documents and Reference 7 presents the results to date of the preliminary international agreements among the British, French, and United States Governments. Thus, at least fourteen informal or semi-formal documents on proposed FAA noise certification plans have been made available to the aviation community by means of technical societies, task forces, and direct mailings. The comments of the aviation community were solicited and they were invited to submit technical data either in support of or against the criteria and technology proposed in each document. As a result, each document was a refinement over the previous one and represented the current state-of-the-art as interpreted by the FAA.

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Much of the work of Woodall, Reference 3, including the concept of effective perceived noise level, contributed to the development of international standards, Reference 8. The particular definition of effective perceived noise level given in Reference 8 is the one adopted in the Tripartite agreement of Reference 7 and, with Reference 9, accepted by the FAA as indicative of the best current state-of-the-art.

The purpose of this report is to put into definitive form all of the aircraft noise evaluation procedures considered most valid at the present time including those portions of References 8 and 9 that are applicable. Criteria relating to noise levels, distances, and aircraft weight and operation are not included here since they properly belong in the NPRM and all subsequent formal rule-making documents. Also omitted are measurement procedures which are included in a companion report, Reference 10. This report and Reference 10 are the latest evolvements of the informal documents initiated by Woodall for the purpose of supporting formal regulation documents issued by the FAA leading to the certification of aircraft for noise.

2. NOISE EVALUATION PROCEDURE

The total objective evaluation of the subjective effect of aircraft noise is designated "effective perceived noise level" and is derived from physical measurements of the spectral and temporal variations of sound pressure level. Three basic physical properties of sound pressure must be measured; level, frequency distribution, and time variation. More specifically, the instantaneous sound pressure level in each of 24 one-third octave bands of the noise is required for a number of consecutive increments of time during the aircraft flyover.

The method presented in this report for calculating effective perceived noise level is identical to that given in the recommended international standards, References 8 and 9. However, the symbols are different and are chosen to be more compatible with those in common usage in the United States. Acoustical technology, especially the subjective aspects, have expanded too rapidly for standard terminology to keep pace. As a result, recent publications almost always contain some terms or symbols newly coined and this one is no exception. It is important, therefore, that lists of symbols be included and definitions be supplied for all unusual terminology. The list of symbols contained here includes brief but sufficient definition to avoid conceptual conflicts among the various quantities. More detailed definitions are given in SAE ARP 865, Reference 11; Kryter, Reference 12; and SAE Draft ARP 1071, Reference 13. The symbols used here are often in multi-letter form and have no subscripts. Where a subscript would normally be used to identify one of many quantities, a parenthetical expression is appended. For example, SPL(i) means the sound pressure level at a given instant of time that occurs in the i-th one-third octave band. The reason for choosing symbols that can be written on a line without suppression is strictly for simplicity in manuscript typing. Very little, if any, confusion should result and the added simplicity might help minimize errors. Computer print-outs are generally in this form, so most investigators should not find it strange.

The calculation method which utilizes physical measurements of noise to derive subjective response is detailed in Sections 8 through 13 and supporting information and examples are given in Appendices A through E. The method, which conforms to the recommended international standards, References 8 and 9, consists of the following five steps:

(1) Instantaneous perceived noise levels are calculated for each noise spectrum occurring at consecutive increments of time during the aircraft flyover. The calculation method uses 24 one-third octave bands of sound pressure level similar to the SAE ARP 865 method of Reference 11, but uses instantaneous instead of peak values and uses the noy modifications of Pinker, Reference 14.

(2) A correction factor is calculated for each spectrum to account for the subjective response to the presence of the maximum tone. The tone correction method is identical to that developed by Bishop, Reference 15, but is presented with different symbols and format.

(3) The tone correction factor is added to the perceived noise level to obtain tone corrected perceived noise levels at given instants of time. The instantaneous values of tone corrected perceived noise level are plotted with respect to time and the maximum value is determined.

(4) A duration correction factor is computed by integration under the curve of tone corrected perceived noise level versus time or by using an alternate approximate method.

(5) Effective perceived noise level is determined by the algebraic sum of the maximum tone corrected perceived noise level and the duration correction factor.

3. GENERAL CONCEPT

Effective perceived noise level, simply stated, consists of instantaneous perceived noise level corrected for tones and flyover duration. This general concept is considered by the FAA Office of Noise Abatement to be reasonable and valid. Furthermore, the five-step procedure described above, which is identical to that recommended by the International Standards Organization, References 8 and 9, which forms part of the Tripartite agreement, Reference 7, is considered by the FAA Office of Noise Abatement to be the best current state-of-the-art.

Most members of the aviation community have supported the concept of effective perceived noise level in principle; that is, some form of perceived noise level corrected for tones and duration but have not necessarily advocated any particular calculation method. SAE Committee R2.5, Reference 16, states: "... The EPNL scale is believed to rate aircraft noise quantitatively better than any other scale presently in use for this purpose... The method of calculating EPNL is not considered to be finalized at this date. It is believed to be a better scale for use in relating complete aircraft flyover noise cycles to each other than peak PNL..." SAE Committee A-21, Reference 17, introduces some reservations by stating: "... Committee A-21 indicated its unanimous support of the concept of Effective Perceived Noise Level, but expressed reservations concerning the lack of agreement on detailed definition of this unit..." The Aerospace Industries Association, Reference 18, introduces a negative opinion by stating: "... Further, while the AIA supports in principle a unit of measure similar to EPNL (EPNdB), we are convinced that this unit as described in your proposal is not suitable for Noise Certification purposes at this time..." Also, the Aerospace Industries Association in a later letter, Reference 19, adopts a regressive point of view by stating: "... AIA members expressed strong opposition to EPNL for certification purposes until such time that engineering experience is acquired in predicting and measuring flyover noise using this unit... AIA members recommended that PNL be used for certification..."

The criticism that has been leveled by some of the aviation community members at the calculation methods of References 3, 8, and 9, is on the basis that they are (1) too complex, (2) not complete, (3) not exact, and (4) unsuitable for prediction. No alternatives have been proposed, however, except the concept of peak perceived noise level given in SAE ARP 865, Reference 11, or a curve of maximum perceived noise level modified by an aircraft altitude correction factor presented by the AIA, Reference 19. The latter is similar to a prediction curve used by SAE Committee R2.5, Reference 16. Neither of these alternatives is satisfactory to the FAA Office of Noise Abatement because they retrogress from the basic concept which most members of the aviation community profess to support. Peak or maximum perceived noise level contains no adjustments for tones and duration.

The basis for the AIA curve, submitted to the FAA in the meeting of Reference 20, indicated so much data scatter than an envelop, instead of a single line curve, would be more appropriate. This subject is discussed in more detail in Appendix E where the results of recent tests are presented in Figures E1(a), (b), (c), and (d). Furthermore, the AIA, Reference 19, states that the recommended curve is based upon the noise of two different types of current engines, both from the same manufacturer, some with a specific tone and some without. However, noise certification is directed primarily toward new aircraft, many of which may have propulsion cycles and lifting devices generating sounds substantially different in character from current aircraft. Everyone concerned believes that tones and duration are legitimate evaluation factors, consequently, the noise certification rule should recognize these factors now to insure the control of potentially obnoxious sounds of the future.

The particular aspects of the criticism directed to the calculation methods, complexities, completeness, exactness, and prediction, are examined in depth in the following four sections.

4. COMPLEXITIES

The FAA Office of Noise Abatement recognizes that the five-step procedure is cumbersome and that effort should be devoted to simplifying the calculation method. Nevertheless, procedures equally or more complicated have been programmed for electronic computers which then permitted results to be easily obtained in a routine manner; e.g., Hecker and Kryter, References 21 and 22.

One objective of this report is to clarify the ISO procedure of References 8 and 9 by casting it in terms familiar to the American aviation community, using a slightly different format, and supplying a number of examples. It may then be apparent that the calculation method is not too complex and can be programmed for electronic computation without great difficulty. It would be very desirable, of course, to have a procedure which would yield acceptable results from simple techniques of sound measurement and data analysis and which could be evaluated in short order by hand calculations. This is an ideal which, probably, never will be realized because it is unrealistic. There is no reason to expect that equipment as complex as aircraft, where virtually every design aspect utilizes highly sophisticated technology, should have any the less complex noise signature consisting of spacial, spectral, and temporal variations of sound pressure.

The noise signature and its mechanisms of generation and suppression may well be one of the least understood characteristics of aircraft. Sperry, Reference 23, examines the general problem of aircraft noise, identifies it with the scientific discipline of non-linear acoustics, presents a catalog of equations of acoustics and fluid dynamics which emphasizes the need for developing and exploiting second order theory. It is conceivable that, instead of being too complex, the procedure does not take into account enough noise signature characteristics to permit proper evaluation of all of the factors influencing human response. For example, narrower frequency band widths than one-third octave might be better. However, the five-step procedure and the related calculation method are considered by the FAA Office of Noise Abatement to be reasonable and amenable to modern computational techniques and, until further research advancements are made, the required measurements are considered necessary and sufficient for the current state-of-the-art.

5. COMPLETENESS

The FAA Office of Noise Abatement recognizes that the five-step procedure is not complete and that more research is necessary on human response to noise, as well as the physical mechanisms of noise generation and suppression, in order to make the effective perceived noise level concept applicable to a wider range of sounds including sonic boom. The ultimate goal is to develop an objective procedure that will accurately evaluate the subjective effects of noise from all current and future transportation equipment as well as current aircraft, including high bypass engine, V/STOL, and supersonic aircraft, and automobile, truck, railway, and air cushion ground vehicles. Considerable noise abatement research programs and studies which have an influence on effective perceived noise level have been performed, are presently underway, and are in the planning stage.

The present form of effective perceived noise level evaluates four factors of the noise signature; level, broadband frequency distribution, maximum tone, and duration. Other factors may be important as well. For example, Ollerhead, Reference 24, reports on the influence of the Doppler shift on subjective ratings of noise from various aircraft. This effect should be explored in more detail and if significant, a Doppler correction factor should be included in a revised form of effective perceived noise level. Other spectral and temporal characteristics such as multiple tones, frequency and amplitude modulation of tones, slowly varying lift pressures, and infra-sonic frequencies might influence subjective response as well. These characteristics and others ultimately will be investigated and the concept modified to include all influential factors. In addition, more work is needed on the speech interference effects of human response which up to now has been concerned primarily with a mixture of loudness and annoyance. However, until such time as further research advancements are made, the FAA Office of Noise Abatement considers the four factors included in the five-step procedure to be necessary and sufficient for the current state-of-the-art.

6. EXACTNESS

The FAA Office of Noise Abatement recognizes that the five-step procedure is not exact and that the objective evaluations of the subjective effects of one or more of the four noise signature factors currently included in the procedure may need adjustment or refinement. The effects of level and frequency distribution of the broadband portion of the spectra are determined by the first step of the procedure - instantaneous perceived noise level. Very little objection has been raised by members of the aviation community with regard to this aspect and what there is relates to the use of peak instead of maximum perceived noise level. Most of the criticism has been directed to the duration correction and very little to the tone correction.

It must be emphasized that the field of psychoacoustics is not yet an exact science and probably never will be. It deals with judgement decisions by human beings on their response to such indefinite characteristics of noise as loudness, annoyance, noisiness, unwantedness, and speech interference. Results are obtained from statistical analyses which may have several interpretations and, because the tests are subjective, can be significantly influenced by testing bias. The latter can result from such causes as preconceived ideas of the principal investigator, test environment, instructions to the test subjects, choice of test subjects, type of sound equipment, choice of reference and test sounds, and methods of comparing sounds. Valid conclusions can best be drawn from the results of many investigators who have conducted their testing under conditions somewhat different from each other. In this way, the testing bias and various statistical interpretations, which will always be present in subjective studies, will have the opportunity to be more randomly oriented.

In its history of development, the tone correction concept has experienced some but not many conflicting results. The principal investigators in this area are practically unanimous in their agreement that for noise that contains audible tones, the best correlation of objective evaluations with subjective ratings results when some form of tone correction is used. They are not, however, in unanimous agreement on which calculation method is superior. On the other hand, the duration correction concept, in its history of development, has experienced considerable controversy. Some principal investigators are convinced that a duration correction, at least by the methods proposed for calculation so far, degrades the accuracy of subjective ratings. The pros and cons of the effects on subjective ratings of both tone and duration corrections are presented below in the form of brief reviews of a number of research papers and reports.

Little, Reference 25, reporting on investigations of steady state noise spectra with and without tones, concludes: "... The use of the PNdB system does not adequately assess the annoyance of spiked noise..."

Wells and Blazier, Reference 26, also reporting on investigations of steady state noise spectra with and without tones, found that a pure tone imposed on a broadband background increased the noisiness of the composite noise relative to the noisiness of the broadband noise without pure tones.

Kryter and Pearson, Reference 27, also reporting on investigations of steady state noise spectra with and without tones found: "... The results clearly show that, for the sounds used in this study, the overall SPL or the perceived noise level in PNdB calculated according to prescribed procedures would underestimate the judged noisiness of the bands of noise containing a strong pure tone relative to the judged noisiness of the bands of noise without the pure tone; ..."

Bishop, Lyden, and Horonjeff, Reference 28, reporting on investigations of aircraft flyover noise, found that subjective ratings were not influenced by flyover duration. They state: "... Little difference was observed between approach and flyover judgements even though the approach flyovers had, on the average, significantly shorter time durations than the takeoff flyovers. These results, then, suggest that the possible changes in noisiness ratings produced by differences in flyover signal time duration, or by presence of strong pure tone components in the flyover signal; are compensating factors in making compositive noisiness judgements of approach and takeoff noise; or possibly are not factors of large enough magnitude to require consideration in evaluating flyover noise signals of current jet aircraft ..."

Pearsons, Reference 29, investigated both the effects of duration and background noise level on the subjective ratings of aircraft noise recordings. He concluded: "... Previous tests have shown that an increase in the duration of an aircraft noise signal produces an increase in its judged noisiness. A combination of all previous and current data indicates that the slope showing the effect of duration on perceived noisiness is continuously varying over the range of durations from 1.5 to 64 seconds... The examination of background noise made during this study suggests that the presence of background noise reduces the judged noisiness of an aircraft flyover..."

Kryter, Reference 30, reports some conflicting results regarding the tone correction concept. He states: "... (2) The presence of either modulated or unmodulated pure tones imposed on a broadband background noise did not increase the noisiness of the broadband sound without pure tones..." Kryter qualifies these results by pointing out that they are in conflict with the results of Little, Reference 25, Wells and Blazier, Reference 26, and other unpublished work by himself and associates. He suggests the disagreement is associated with the method of judgement tests employed in the investigations of noisiness. The above quoted results from Reference 30 used the method of individual adjustments whereas the other referenced work used the method of paired-comparisons.

Pearsons, Reference 31, conducted judgement tests on the noisiness of helicopter noises and compared the results with PNL, N-level, A-level, and OASPL. He concludes: "... (1) As a predictor of the noisiness of helicopter flyovers, the calculated perceived noise level provides the most accurate measure of the four objective measures included in this investigation. The N-level and A-level, although slightly less accurate, were also reasonable predictors, followed finally by the overall SPL. (2) Duration and pure-tone correction did not improve the predictability of the noisiness of the helicopter flyover noise samples under test, possibly due to inadequate duration measures or a factor in the additivity of the duration adjustment not previously tested..."

Pearsons and Horonjeff, Reference 32, reported the effects of tone and duration on the subjective ratings of aircraft noise recordings. They used the tone adjustment method of Reference 27 and the duration adjustment method of Reference 29 and found only slight improvement for the adjusted perceived noise level over the peak perceived noise level but N-level seemed to provide the best measure of subjective noisiness. Field tests of aircraft flyovers were also conducted and the highest correlation between the noisiness rating scale and the physical measures of peak PNL, A-level, N-level and overall SPL was provided by peak PNL. No increase in correlation was observed by adjusting the perceived noise level to account for the duration and pure tone content.

Williams, Stevens, Hecker, and Pearsons, Reference 33, reported that time varying noise provided less masking of speech than steady state noise. They also state: "... (5) If two aircraft flyovers differ in duration by a factor of two, the peak level of the flyover having the longer duration must be 2.5 to 4.0 PNdB less than that of the other flyover if the two are to be judged equally acceptable. This finding supports previously obtained data..." (Reference 29.)

Pearsons, Horonjeff, and Bishop, Reference 34, investigated subjective judgements of single, modulated, and multiple tones plus noise. They state: "... In general, pure tone corrections were necessary, the exception being situations in which the pure tone is added to an octave band of noise ..." They also conclude: "... 6. The pure tone corrections obtained using pure tones in broadband noise agree with previous results; however, those obtained using octave bands of noise do not. 7. The maximum correction necessary for the additional noisiness of a pure tone seems to occur at a tone-to-noise ratio of 25 dB as measured in a one-third octave band. Comparisons between tones at this tone-to-noise ratio and tones without noise present are quite similar..."

Wells, Reference 35, reporting on the progress of subjective noise studies at the General Electric Co., states: "... In the aircraft industry in particular, the calculation of PNdB has come into wide

usage. However, it has been recognized for several years that this calculation doesnot agree well with actual subjective jury tests for cases where the noise spectra involve strong pure tones..."

Little and Mabry, Reference 36, discuss the state-of-the-art of human response to aircraft noise. They apparently have no basic objection to the tone correction concept except, perhaps, that the calculation procedure of Reference 3 is not severe enough because they state: "... In a study just completed by Dunlap and Associates for Pratt and Whitney Aircraft, the tone corrections were found to be half that required to match subject's responses..." Referring to recent studies conducted at the Boeing Co., they state: "... The use of tone corrections provided better results than PNL by itself. However, in all cases, the addition of the duration factor increased error..."

Ollerhead, Reference 24, conducted judgement tests on various recorded aircraft sounds, mostly from general aviation type aircraft. He found conflicts with duration corrections and support for tone corrections. He states: "... A significant finding which the analysis revealed is that the sound duration, defined conventionally as the interval between the 10 dB-down points, has very little affect on judged noisiness of the sounds studied. Duration corrections when applied to five different rating methods substantially degraded the performance of these methods as noise predictors. The study suggests that an explanation for this may lie in the effects of the Doppler frequency shift which hitherto has not been accounted for in any accepted rating scheme... Ignoring this Doppler shift correction, it was found that the pure tone corrected perceived noise level, PNdBF, is currently the most satisfactory general purpose predictor of subjective noise evaluation..."

Hecker and Kryter, Reference 21, evaluated various established and proposed objective methods of measuring aircraft noise with respect to their ability to predict subjective ratings of the acceptability of noise produced by present-day commercial aircraft. They conclude: "... The smallest variance was associated with EPNdBt, a measure that takes into account the spectral properties of a given flyover for its entire duration and also the presence of pure tones or other narrowband energy concentrations... The successful design of this measure must undoubtedly be attributed both to the integration method of calculating effective perceived noise level and to the method of tone correction by Little..."

Kryter, Reference 22, conducted judgement tests of aircraft flyover noise in conjunction with a sonic boom test program. His results substantiated the conclusions of Reference 21.

Hinterkeuser and Sternfeld, Reference 37, conducted judgements on synthesized flight noise signatures of V/STOL aircraft. They applied tone and duration corrections in accordance with an early revision to

Reference 2. They state: "... Although the statistical evaluation on Figure 15 does not show any great significant effects of the corrections, this is not necessarily true for individual cases. In fact, these corrections can only be evaluated for those specific cases to which corrections apply. Since the cruise operation involves elapsed times close to 15 seconds, no correction is evident. The terminal operation, however, involves substantially longer times, and an improvement in correlation, due to inclusion of duration correction, is noted in all cases... Pure tone components are most strongly evident during terminal operations of the fan lift, jet lift, and turbofan STOL aircraft. In these cases, a significant improvement in correlation is indicated by inclusion of the pure tone correction factor..."

The results of sixteen investigations on the subjective ratings of aircraft noise were briefly reviewed for their conclusions on tone and duration corrections. Some controversy exists but the preponderance of evidence indicates that both tone and duration corrections are required. Hence, the FAA Office of Noise Abatement considers them valid as well and, until further research advancements are made, the calculation method of the five-step procedure is considered sufficiently exact for the current state-of-the-art.

7. PREDICTION

The basic problem that the aviation community has with the noise evaluation procedure presented in this report is the inability of the manufacturers to predict the noise of paper aircraft to the degree of refinement implied by the procedure. It is possible, however, that the problem of prediction refinement is overemphasized. Approximate methods of calculation are available and others can be developed that might yield results not too different from the more complex method. This would be particularly true if sufficient noise abatement is designed into the aircraft to eliminate the presence of tones. The subject of approximate methods is discussed in more detail in Appendix E.

There are valid reasons why the noise evaluation procedure should have a high degree of refinement. First, it must be emphasized that the procedure involves a computational method which utilizes physical measurements of actual aircraft flyovers. And, as long as the aircraft exist and noise measurements are going to be made, it would be advantageous to obtain as much information on the noise signature as is practical. Second, once this information is available, it does no harm to utilize it thoroughly even though for particular cases, less complex methods might yield approximately the same answers. The calculation method proposed here is not difficult to apply with the aid of electronic computers and there is always the possibility that new types of aircraft will have noise signatures that require more detailed data and sophisticated analyses to accurately evaluate subjective response than do current aircraft.

The prediction of aircraft noise can have more than one meaning and can be accomplished in various ways. If the noise is to be predicted in terms of physical properties (such as the instantaneous sound pressure level in each of 24 one-third octave bands of noise for a number of consecutive increments of time during aircraft flyovers), the task will be difficult and the accuracy of the predicted level for any given frequency band, SPL(i), may be poor. The current state-of-the-art does not have the sophistication to include all of the effects of the mechanisms of sound generation, suppression, propagation, and radiation necessary to accurately predict detailed physical properties. This is an important deficiency in the technology of aircraft noise abatement that is recognized by all knowledgeable workers in the area and for which substantial effort to amend is being devoted by government and industry.

If the noise is to be predicted in terms of subjective response such as a perceived noise level (PNLP, PNLM, PNLTM, or EPNL), the task will be much less difficult and the accuracy much better than for the case of physical property prediction. The subjective response prediction is a single number evaluation of estimated physical properties, and the current state-of-the-art is remarkably insensitive to wide variations

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in physical details. This is another deficiency which, probably, contributes to the data scatter in the psychoacoustics judgement tests and for which substantial effort to amend is also being devoted by government and industry.

Of the four perceived noise level evaluators listed above, the least sensitive to physical details is peak perceived noise level, PNLP, and the most sensitive is effective perceived noise level, EPNL. However, there is not a great deal of difference in sensitivity between them and the issue must not be allowed to be clouded by confusing the prediction capabilities for human response with those for detailed physical properties.

8. PERCEIVED NOISE LEVEL

Instantaneous perceived noise level, PNL, is calculated according to the following three-step procedure:

Step 1.

Convert each measured one-third octave band sound pressure level from 50 to 10,000 Hz, SPL(i), that occurs at any given instant of time to perceived noisiness, n(i), by reference to Table 8.1.

Step 2.

The noy values, n(i), found in Step 1 are combined in the manner prescribed by the following formula:

$$N = \underline{n} + 0.15 \left[\sum_{i=1}^{24} n(i) - \underline{n} \right] \tag{8.1}$$

where $\underline{n}$ is the number of noys in the noisiest band and N is the total noy value.

Step 3.

The total perceived noisiness, N, is converted into perceived noise level, PNL, by means of the following formula:

$$PNL = 40 + 33.3 \log N \tag{8.2}$$

which is plotted in Figure 8.1. PNL can also be obtained by choosing N in the 1,000 Hz column of Table 8.1 and reading the corresponding value of SPL which, at 1,000 Hz, is identically equal to PNL.

The mathematical formulation of the Noy Table is given in Appendix A and examples of PNL calculations are given in Appendix B.

SPL dB	One-Third Octave Band Center Frequencies f, HZ																							
	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table 8.1 NOYs As a Function of Sound Pressure Level.

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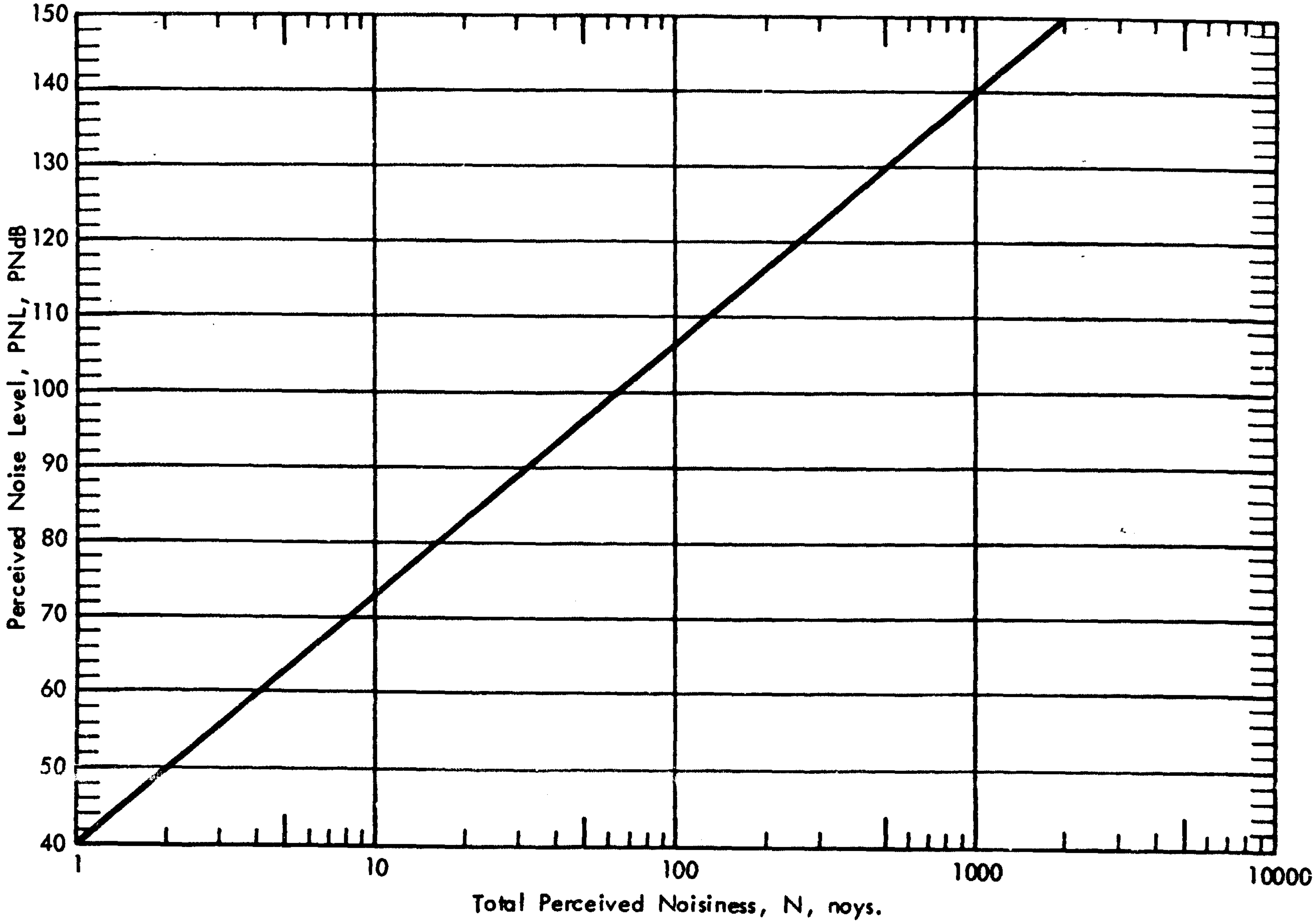


Figure 8.1. Perceived Noise Level as a Function of Noys.

9. TONE CORRECTION

Noise having pronounced irregularities in the spectrum (for example, discrete frequency components or tones), is adjusted by the correction factor C calculated in accordance with the ten-step procedure defined below.

Step 1.

Starting with the measured sound pressure level in the 80 Hz one-third octave band (band number 3), calculate the changes in level (or "slopes") in the remainder of the 24 bands as follows:

$$s(3) = \text{no value} \tag{9.1}$$

$$s(4) = SPL(4) - SPL(3) \tag{9.2}$$

$$\vdots$$

$$s(i) = SPL(i) - SPL(i-1) \tag{9.3}$$

$$\vdots$$

$$s(24) = SPL(24) - SPL(23) \tag{9.4}$$

Step 2.

Encircle the value of the slope s(i) where the absolute value of the change in slope is greater than five; that is, where

$$|\Delta s(i)| = |s(i) - s(i-1)| > 5 \tag{9.5}$$

Step 3.

(a) If the encircled value of the slope s(i) is positive and algebraically greater than the slope s(i-1), encircle the level SPL(i).

(b) If the encircled value of the slope $s(i)$ is zero or negative and the slope $s(i-1)$ is positive, encircle the level $SPL(i-1)$.

(c) For all other cases, no level is to be encircled.

Step 4.

Omit all $SPL(i)$ encircled in Step 3 and compute new levels as follows:

(a) For non-encircled levels, let the new levels equal the original levels,

$$SPL'(i) = SPL(i) \tag{9.6}$$

(b) For encircled levels, let the new level equal the arithmetic average of the preceding and following levels,

$$SPL'(i) = 1/2 \left[SPL(i-1) + SPL(i+1) \right] \tag{9.7}$$

(c) If the level in the highest frequency band is encircled, let the new level equal

$$SPL'(24) = SPL(23) + s(24) \tag{9.8}$$

Step 5.

Recompute new slopes including one for an imaginary 25-th band as follows:

$$s'(3) = s'(4) \tag{9.9}$$

$$s'(4) = SPL'(4) - SPL'(3) \tag{9.10}$$

.
.
.

$$s'(i) = SPL'(i) - SPL'(i-1) \tag{9.11}$$

.
.
.

$$s'(24) = SPL'(24) - SPL'(23) \tag{9.12}$$

$$s'(25) = s'(24) \tag{9.13}$$

Step 6.

Compute the arithmetic average of the three adjacent slopes as follows:

$$\bar{s}(i) = 1/3 \left[s'(i) + s'(i+1) + s'(i+2) \right] \qquad (9.14)$$

Step 7.

Compute final adjusted levels by beginning with band number 3 and proceeding to band number 24 as follows:

$$SPL''(3) = SPL(3) \qquad (9.15)$$

$$SPL''(4) = SPL''(3) + \bar{s}(3) \qquad (9.16)$$

.

.

.

$$SPL''(i) = SPL''(i-1) + \bar{s}(i-1) \qquad (9.17)$$

.

.

.

$$SPL''(24) = SPL''(23) + \bar{s}(23) \qquad (9.18)$$

Step 8.

Calculate the difference between the original and adjusted levels as follows:

$$F(i) = SPL(i) - SPL''(i) \qquad (9.19)$$

and note only values greater than zero.

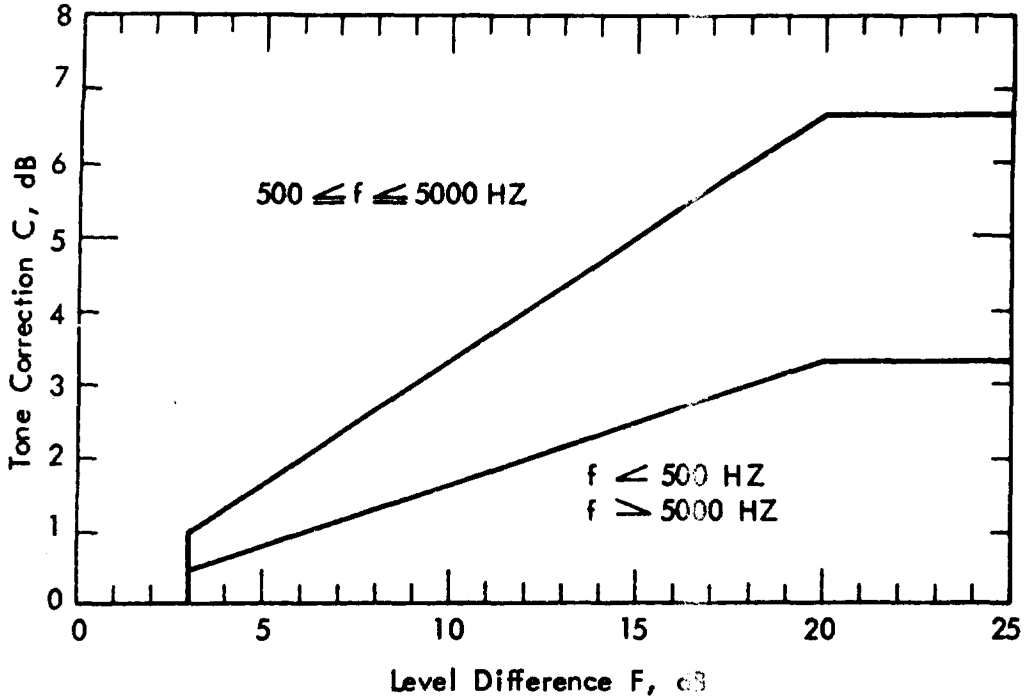
Step 9.

Tone correction levels C are determined for any one-third octave band in accordance with Table 9.1. However, only the maximum one is important.

Step 10.

The maximum value of C determined in Step 9 defines the tone correction that is to be added to the perceived noise level PNL to obtain the tone corrected perceived noise level PNLT.

Examples of the tone correction procedure are given in Appendix C.



Frequency f, HZ	Level Difference F, dB	Tone Correction C, dB
$50 \leq f < 500$	$F < 3$ $3 \leq F < 20$ $20 \leq F$	0 F/6 3 1/3
$500 \leq f \leq 5000$	$F < 3$ $3 \leq F < 20$ $20 \leq F$	0 F/3 6 2/3
$5000 < f \leq 10000$	$F < 3$ $3 \leq F < 20$ $20 \leq F$	0 F/6 3 1/3

Table 9.1. Tone Correction Factors

10. MAXIMUM TONE CORRECTED PERCEIVED NOISE LEVEL

The maximum tone corrected perceived noise level, PNLTM, is the maximum value determined from a smooth curve of the values of the tone corrected perceived noise level, PNLT, calculated in accordance with the procedure of Section 9, plotted against the flyover time, t. Figure 10.1 is an example of a flyover noise time history where the maximum value is clearly indicated. Half-second time intervals, Δt, will usually be small enough to obtain a satisfactory noise time history. The other symbols shown in Figure 10.1 are defined in Section 11.

If there are no pronounced irregularities in the spectrum, then the procedure of Section 9 would be redundant since PNLT would be identically equal to PNL. For this case, PNLTM would be the maximum value of the curve of PNL versus t, that is, it would equal PNLM.

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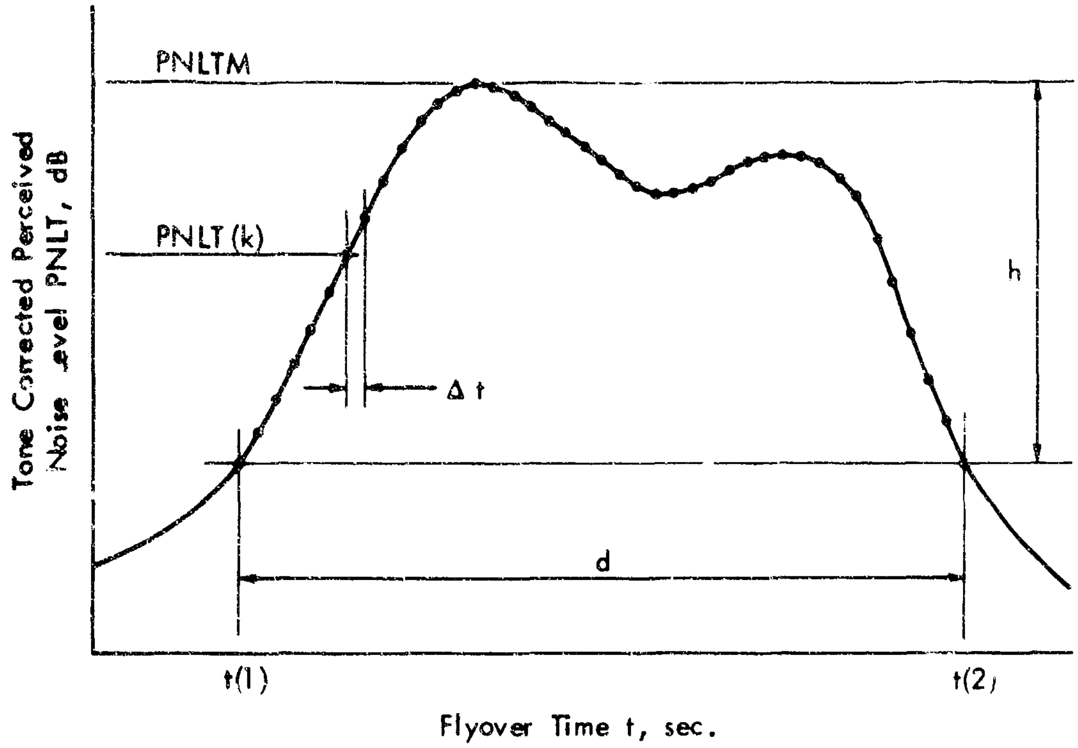

Figure 10.1. Perceived Noise Level Corrected for Tones as a Function of Aircraft Flyover Time

11. INTEGRATED DURATION CORRECTION

The integrated duration correction D is defined by the expression:

$$D = 10 \log \left[(1/T) \int_{t(1)}^{t(2)} \text{ant} \quad (PNLT/10)dt \right] - PNLTM \tag{11.1}$$

where T is a normalizing time constant, PNLT is the expression for tone corrected perceived noise level as a function of time, PNLTM is the maximum value of the tone corrected perceived noise level, and t(1) and t(2) are the limits of the time interval d during which PNLT is within a specified value h of PNLTM. Figure 10.1 illustrates the above conditions.

Since PNLT is calculated from measured values of SPL, there will, in general, be no obvious equation for PNLT as a function of t. Consequently, Equation (11.1) can be rewritten with a summation sign instead of the integral sign as follows:

$$D = 10 \log \left[(1/T) \sum_{k=0}^{d/\Delta t} \Delta t \quad \text{ant} \left[PNLT(k)/10 \right] \right] - PNLTM \tag{11.2}$$

where Δt is the equal increment of time for which PNLT is calculated and PNLT(k) is the value of PNLT at the k-th increment of time.

At this date, the following values are considered representative of the current state-of-the-art for the integration procedure and are presented as basic requirements:

$$T = 10 \text{ sec} \tag{11.3}$$

$$\Delta t = 0.5 \text{ sec} \tag{11.4}$$

$$h = 10 \text{ dB} \tag{11.5}$$

Using the above values, Equation (11.2) becomes,

$$D = 10 \log \left[\sum_{k=0}^{2d} \text{ant} \left[PNLT(k)/10 \right] \right] - PNLTM - 13 \tag{11.6}$$

where d is the duration time defined by the 10 dB-down points.

Examples of duration correction calculations are given in Appendix D.

12. APPROXIMATE DURATION CORRECTION

The integrated duration calculation procedure presented in Section 11 is considered to be most representative of the current state-of-the-art. However, an alternative method is given below which is simpler to use but yields, in general, larger duration correction values.

The approximate duration correction D is defined by the expression:

$$D = 10 \log (d/T) \tag{12.1}$$

where d is the time interval between the limits of t(1) and t(2) during which PNLT is within a specified value h of PNLTM and T is a normalizing time constant. At this date, the following values are considered representative of the current state-of-the-art for the approximate procedure and are presented as basic requirements:

$$T = 15 \text{ sec.} \tag{12.2}$$

$$h = 10 \text{ dB} \tag{12.3}$$

Using the above values, Equation (12.1) becomes

$$D = 10 \log (d/15) \tag{12.4}$$

where d is the duration time defined by the 10 dB-down points.

Examples of duration correction calculations are given in Appendix D including comparisons between the two procedures.

13. EFFECTIVE PERCEIVED NOISE LEVEL

The total subjective effect of an aircraft flyover is designated "effective perceived noise level," EPNL, and is equal to the algebraic sum of the maximum value of the tone corrected perceived noise level, PNLTM, and the duration correction, D. That is,

$$\mathrm{EPNL} = \mathrm{PNLTM} + D \tag{13.1}$$

where PNLTM and D are calculated in accordance with the procedures given in Sections 8, 9, 10, 11, and 12 and as illustrated in Appendices A, B, C, and D.

If the integrated calculation procedure is used, Equation (13.1) can be rewritten by substituting Equation (11.6) for D; that is,

$$\mathrm{EPNL} = 10 \log \left[\sum_{k=0}^{2d} \mathrm{ant} \left[\mathrm{PNLT}(k)/10 \right] \right] - 13 \tag{13.2}$$

14. SUMMARY

The primary element in any procedure for certificating aircraft noise is the evaluation measure upon which the criteria is based. Aircraft noise signatures, which involve interrelated spectral, temporal, and spacial functions of sound pressure, are so complex that the search for a suitable single number noise evaluator has been long and difficult. The end result to date, considered the best current state-of-the-art by the FAA Office of Noise Abatement, is effective perceived noise level, EPNL.

This opinion, however, is not shared by some members of the aviation community who would prefer a simpler evaluator such as perceived noise level, PNL. This simpler measure responds to the effects of frequency and level but does not permit the adjustments for the annoyance of strong tones and long durations that are inherent in EPNL.

It is extremely important that the noise evaluator chosen for certification be versatile in the sense that it recognizes the annoyance effects known today and is capable of modification or refinement for potentially obnoxious sounds of the future. EPNL is such a unit; not complete and not exact, but the best available at the present time. Furthermore, it is not too complex and it is suitable for prediction.

Documentation in support of the above opinions has been presented in the preceding sections. Detailed effort has been devoted to the specific criticisms proffered by those members of the aviation community that are not in accord.

The specific noise evaluation procedure recommended by ISO, References 8 and 9, has been delineated and rewritten with symbols chosen to be more compatible with those in common usage in the United States.

Examples of the various computational procedures that are basic to EPNL are given in the Appendices. Also included is a discussion on approximate methods for determining EPNL which may be suitable for prediction unless the aircraft sounds of the future are radically different from those of today.

15. REFERENCES

1. "An Act to Amend the Federal Aviation Act of 1958 to Require Aircraft Noise Abatement Regulation, and for Other Purposes," Public Law 90-411, 90th Congress (H. R. 3400 and S 707), July 21, 1968.

2. "Proposed FAA Maximum Allowable Noise Levels to be Required for Certification of Future Aircraft," Enclosed with letter by Joseph D. Blatt, September 1, 1966.

3. Woodall, J. F., and Advisors, "Aircraft Development Service Proposal for FAA Noise Certification Criteria," Sixth Revision to Reference 1, February 1, 1968.

4. Hoover, I. H., "Aircraft Noise Certification Alternatives," Letter to the aircraft industry manufacturers, operators, and consultants, October 3, 1967.

5. Systems Analysis Staff, Office of Noise Abatement, "Aircraft Noise Analysis and Measurement," Federal Aviation Administration, Draft Advisory Circular, Third Revision, May 17, 1968.

6. "Aircraft Noise Measurement and Description Near an Airport," Department of Transportation, Federal Aviation Administration, Advisory Circular, ~~June 14, 1968~~. Unpublished

7. "Draft Aircraft Noise Certification Plan," Tripartite Meeting, Washington, D. C., Second Revision, May 1, 1968.

8. "Procedure for Describing Aircraft Noise Around an Airport," International Organization for Standardization, ISO Recommendation R507, Revision November 1967.

9. "Procedure for Describing Aircraft Noise Around an Airport," International Organization for Standardization, ISO Recommendation R507, Amendment, April 1968.

10. Oleson, S. K., and Sperry, W. C., "Aircraft Noise Measurement," Federal Aviation Administration, Report FAA-NO-~~69-2~~, ~~September~~ 1968.
    68-36, November

11. "Definition and Procedures for Computing the Perceived Noise Level of Aircraft Noise," SAE Committee A-21, ARP 865, November 15, 1964.

12. Kryter, K. D., "Concepts of Perceived Noisiness, Their Implementation and Application," Journal of Acoustical Society of America, Vol. 43, No. 2, PP 344-361, October 1967.

13. "Definition and Procedures for Computing the Effective Perceived Noise Level for Flyover Aircraft Noise," SAE Committee A-21, Draft ARP 1071, February 1, 1968.

14. Pinker, R. A., "Computation of Perceived Noise Level: Mathematical Formulation of the Noy Tables," National Gas Turbine Establishment, N. G. T. E. NT. 684, Feburary 1968.

15. Bishop, D. E., "Examples of Revised Procedures for Estimating Broadband Noise Levels from One-Third Octave Band Spectrum Measurements," Bolt, Beranek, and Newman, Inc., Tech. Memo to SAE Committee A-21, February 2, 1968.

16. SAE Research Project Committee R2.5, "Technique for Developing Noise Exposure Forecasts," Federal Aviation Administration, FAA-DS-67-14, August 1967.

17. Minutes of Meeting No. 23, SAE Committee A-21, Aircraft Exterior Noise Measurement, February 7-8, 1968.

18. Aerospace Industries Association (Harr) letter to the Federal Aviation Administration (McKee), 5 December 1967.

19. Aerospace Industries Association (Snodgrass) letter to the Federal Aviation Administration (Paullin), 25 March 1968.

20. Aerospace Industries Association Briefing to the Government/Industry Task Force, July 11-12, 1968.

21. Hecker, M. H. L., and Kryter, K. D., "Comparisons Between Subjective Ratings of Aircraft Noise and Various Objective Measures," Federal Aviation Administration, FAA-NO-68-33, April 1968.

22. Kryter, K. D., "Results of Psychological Experiments Conducted at Edwards Air Force Base for the National Sonic Boom Evaluation Office," National Sonic Boom Evaluation Office, Contract AF49(638)-1758, May 1968.

23. Sperry, W. C., "Governing Equations for Wave Propagation in a Homogeneous, Isotropic, Continuous Fluid," University of Tennessee Space Institute, Short Course on Noise Generation and Suppression in Aircraft, January 29, 1968.

24. Ollerhead, J. B., "Subjective Evaluation of General Aviation Aircraft Noise," Federal Aviation Administration, FAA-NO-68-35, April 1968.

25. Little, J. W., "Human Response to Jet Engine Noise," Noise Control 7, 11-14, No. 3, May - June 1961.

26. Wells, R. J., and Blazier, W. E., "A Procedure for Computing the Subjective Reaction to Complex Noise," Fourth International Congress on Acoustics, Copenhagen, Paper L24, 21-28 August 1962.

27. Kryter, K. D., and Pearsons, K. S., "Judged Noisiness of a Band of Random Noise Containing an Audible Pure Tone," J. Acoust. Soc. Am. 38, No. 1, 106-112, July 1965.

28. Bishop, D. E., Lyden, F. J., and Horonjeff, R. D., "Analysis of Community and Airport Relationships/Noise Abatement," Federal Aviation Agency, FAA-RD-65-130, December 1965.

29. Pearsons, K. S., "The Effects of Duration and Background Noise Level on Perceived Noisiness," Federal Aviation Agency, FAA-ADS-78, April 1966.

30. Kryter, K. D., "Review of Research and Methods for Measuring the Loudness and Noisiness of Complex Sounds," National Aeronautics and Space Administration, NASA CR-422, April 1966.

31. Pearsons, K. S., "Noisiness Judgements of Helicopter Flyovers," Federal Aviation Administration, FAA-DS-67-1, January 1967.

32. Pearsons, K. S., and Horonjeff, R. D., "Category Scaling Judgement Tests on Motor Vehicle and Aircraft Noise," Federal Aviation Administration, FAA-DS-67-8, July 1967.

33. Williams, C. E., Stevens, K. N., Hecker, M. H. L., and Pearsons, K. S., "The Speech Interference Effects of Aircraft Noise," Federal Aviation Administration, FAA-DS-67-19, September 1967.

34. Pearsons, K. S., Horonjeff, R. D., and Bishop, D. E., "The Noisiness of Tones Plus Noise," National Aeronautics and Space Administration, Contract No. NAS 1-6364, 8 September 1967.

35. Wells, R. J., "Recent Research Relative to Perceived Noise Level," Seventy-fourth Meeting of the Acoustical Society of America, Miami Beach, Florida, 14-17 November 1967.

36. Little, J. W., and Mabry, J. E., "Development and Validity of the Noise Unit Called Effective Perceived Noise Level," The Boeing Co., January 15, 1968.

37. Hinterkeuser and Sternfeld, "Subjective Response to Synthesized Flight Noise Signatures of Several Types of V/STOL Aircraft," National Aeronautics and Space Administration Contract No. NAS 1-7083, Boeing Vertol Document D8-0907A, 1968.

38. Bishop, D. E., "Descriptions of Flyover Noise Signals Produced by Various Jet Transport Aircraft," FAA Technical Report, FAA-DS-67-18, August 1967.

39. Fisk, W. S., "Creation of Pseudo Pure Tones and Sensitivity of TPNL Correction to Tolerances on Noise Spectra or Level of Background Noise," G. E. Flight Propulsion Division, Tech. Memo to SAE Committee A-21, November 10, 1967.

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APPENDIX A. MATHEMATICAL FORMULATION OF NOY TABLES

The relationship between sound pressure level and perceived noisiness given in Table 8.1 is illustrated in Figure A1. The variation of SPL with log n for a given one-third octave band can be expressed by either one or two straight lines depending upon the frequency range. Figure A1(a) illustrates the double line case for frequencies below 400 Hz and above 6300 Hz and Figure A1(b) illustrates the single line case for all other frequencies.

The important aspects of the mathematical formulation are:

1. the slopes of the straight lines, p(1) and p(2),
2. the intercepts of the lines on the SPL-axis, SPL(1) and SPL(2), and
3. the coordinates of the discontinuity, SPL(0) and log n(0).

The equations are as follows:

Case 1 Figure A1(a) $f < 400$ Hz and $f > 6300$ Hz.

$$\mathrm{SPL}(0) = \frac{p(2)\ \mathrm{SPL}(1) - p(1)\ \mathrm{SPL}(2)}{p(2) - p(1)} \qquad \text{(A1)}$$

$$\log n(0) = \frac{\mathrm{SPL}(2) - \mathrm{SPL}(1)}{p(1) - p(2)} \qquad \text{(A2)}$$

(a) $\mathrm{SPL}(1) \leq \mathrm{SPL} \leq \mathrm{SPL}(0)$

$$n = \mathrm{ant}\ \frac{\mathrm{SPL} - \mathrm{SPL}(1)}{p(1)} \qquad \text{(A3)}$$

(b) $\mathrm{SPL} \geq \mathrm{SPL}(0)$

$$n = \mathrm{ant}\ \frac{\mathrm{SPL} - \mathrm{SPL}(2)}{p(2)} \qquad \text{(A4)}$$

(c) $0 \leq \log n \leq \log n(o)$

$$\mathrm{SPL} = p(1) \log n + \mathrm{SPL}(1) \qquad \text{(A5)}$$

(d) $\log n \geq \log n(o)$

$$\mathrm{SPL} = p(2) \log n + \mathrm{SPL}(2) \qquad \text{(A6)}$$

<u>Case 2</u> Figure A1(b) $400 \leq f \leq 6300$ Hz

(a) $SPL \geq SPL(2)$

$$n = \text{ant}\ \frac{SPL - SPL(2)}{p(2)} \qquad \text{(A7)}$$

(b) $\log n \geq 0$

$$SPL = p(2)\ \log n + SPL(2) \qquad \text{(A8)}$$

Let the reciprocals of the slopes be defined as

$$M(1) = 1/p(1) \qquad \text{(A9)}$$

$$M(2) = 1/p(2) \qquad \text{(A10)}$$

Then the equations can be written

<u>Case 1</u> Figure A1(a) $f \leq 400$ Hz and $f \geq 6300$ Hz

$$SPL(0) = \frac{M(1)\ SPL(1) - M(2)\ SPL(2)}{M(1) - M(2)} \qquad \text{(A11)}$$

$$\log n(0) = \frac{M(1)\ M(2) \left[SPL(2) - SPL(1) \right]}{M(2) - M(1)} \qquad \text{(A12)}$$

(a) $SPL(1) \leq SPL \leq SPL(0)$

$$n = \text{ant}\ M(1) \left[SPL - SPL(1) \right] \qquad \text{(A13)}$$

(b) $SPL \geq SPL(0)$

$$n = \text{ant}\ M(2) \left[SPL - SPL(2) \right] \qquad \text{(A14)}$$

(c) $0 \leq \log n \leq \log n(0)$

$$SPL = \frac{\log n}{M(1)} + SPL(1) \qquad \text{(A15)}$$

(d) $\log n \geq \log n(0)$

$$SPL = \frac{\log n}{M(2)} + SPL(2) \qquad \text{(A16)}$$

Case 2 Figure A1(b) $400 \leq f \leq 6300$ Hz

(a) $SPL \geq SPL(2)$

$$n = \text{ant } M(2) \left[SPL - SPL(2) \right] \qquad (A17)$$

(b) $\log n \geq 0$

$$SPL = \frac{\log n}{M(2)} + SPL(2) \qquad (A18)$$

Table A1, taken from Reference 14, lists the values of the important constants necessary to calculate sound pressure level as a function of perceived noisiness.

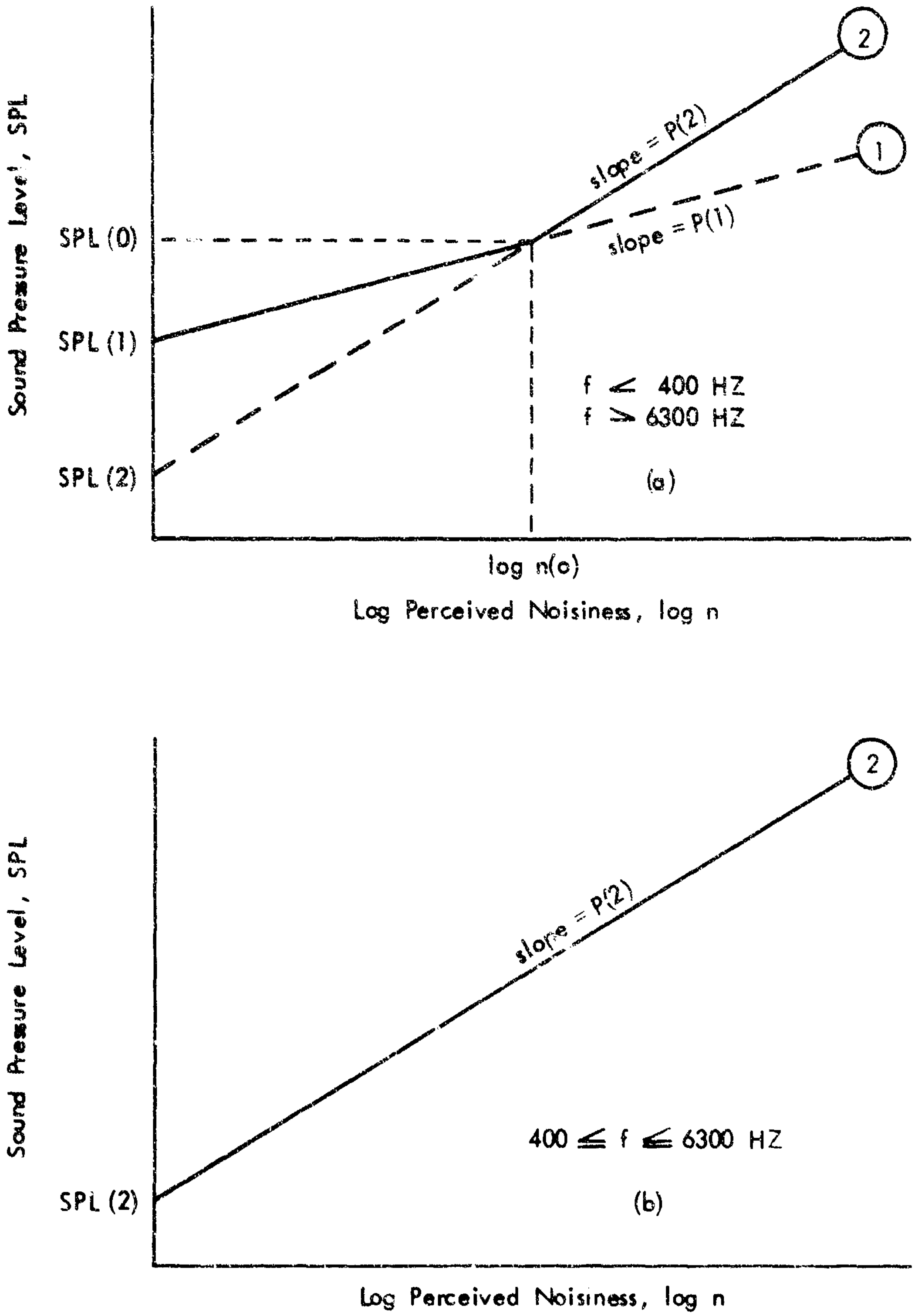

Figure A 1. Sound Pressure Level as a Function of Noys.

Band (i)	f HZ	M(1)	SPL (1) dB	SPL (0) dB	M(2)	SPL (2) dB
1	50	0.043478	64	91.0	0.030103	52
2	63	0.040570	60	85.9	.	51
3	80	0.036831	56	87.3	"	49
4	100	"	53	79.9	"	47
5	125	0.035336	51	79.8	"	46
6	160	0.033333	48	76.0	"	45
7	200	"	46	74.0	"	43
8	250	0.032051	44	74.[illegible]	"	42
9	315	0.030675	42	94.6	"	41
10	400	-	-	-	"	40
11	500	-	-	-	"	"
12	630	-	-	-	"	"
13	800	-	-	-	"	"
14	1000	-	-	-	"	"
15	1250	-	-	-	"	38
16	1600	-	-	-	0.029960	34
17	2000	-	-	-	"	32
18	2500	-	-	-	"	30
19	3150	-	-	-	"	29
20	4000	-	-	-	"	"
21	5000	-	-	-	"	30
22	6300	-	-	-	"	31
23	8000	0.042285	37	44.3	"	34
24	10000	"	41	50.7	"	37

Table A1. Constants for Mathematically Formulated NOY Values

APPENDIX B. EXAMPLES OF PERCEIVED NOISE LEVEL CALCULATIONS

Examples of instantaneous noise spectra are shown in Figure B1(a) for a turbofan engine and in Figure B1(b) for a turbojet engine. The spectra are significantly different. The turbofan engine noise spectrum (taken from Reference 38) contains pronounced irregularities due to a multiplicity of discrete frequency components or tones. The turbojet engine noise spectrum (taken from Reference 39) is relatively smooth indicating broadband noise with no appreciable tones.

Associated with each noise spectra are three different single number noise ratings. The over-all sound pressure level, OASPL, is directly related to the noise energy and, for the particular examples shown, the turbojet produces the greatest noise energy, exceeding the turbofan by 4.5 dB. However, the perceived noise level, PNL, which is a subjective measure, is greater by about one PNdB for the turbofan. This reversal of the energy rating by the subjective rating clearly indicates the influence that high frequency noise has on annoyance.

The third noise rating, tone corrected perceived noise level, PNLT, will be discussed in detail in Appendix C. However, further emphasis of the influence of spectral character on annoyance is indicated by the 2 PNdB greater value of PNLT over PNL for the turbofan engine. For the turbojet engine, the PNL and PNLT values are identical because of the absence of tones.

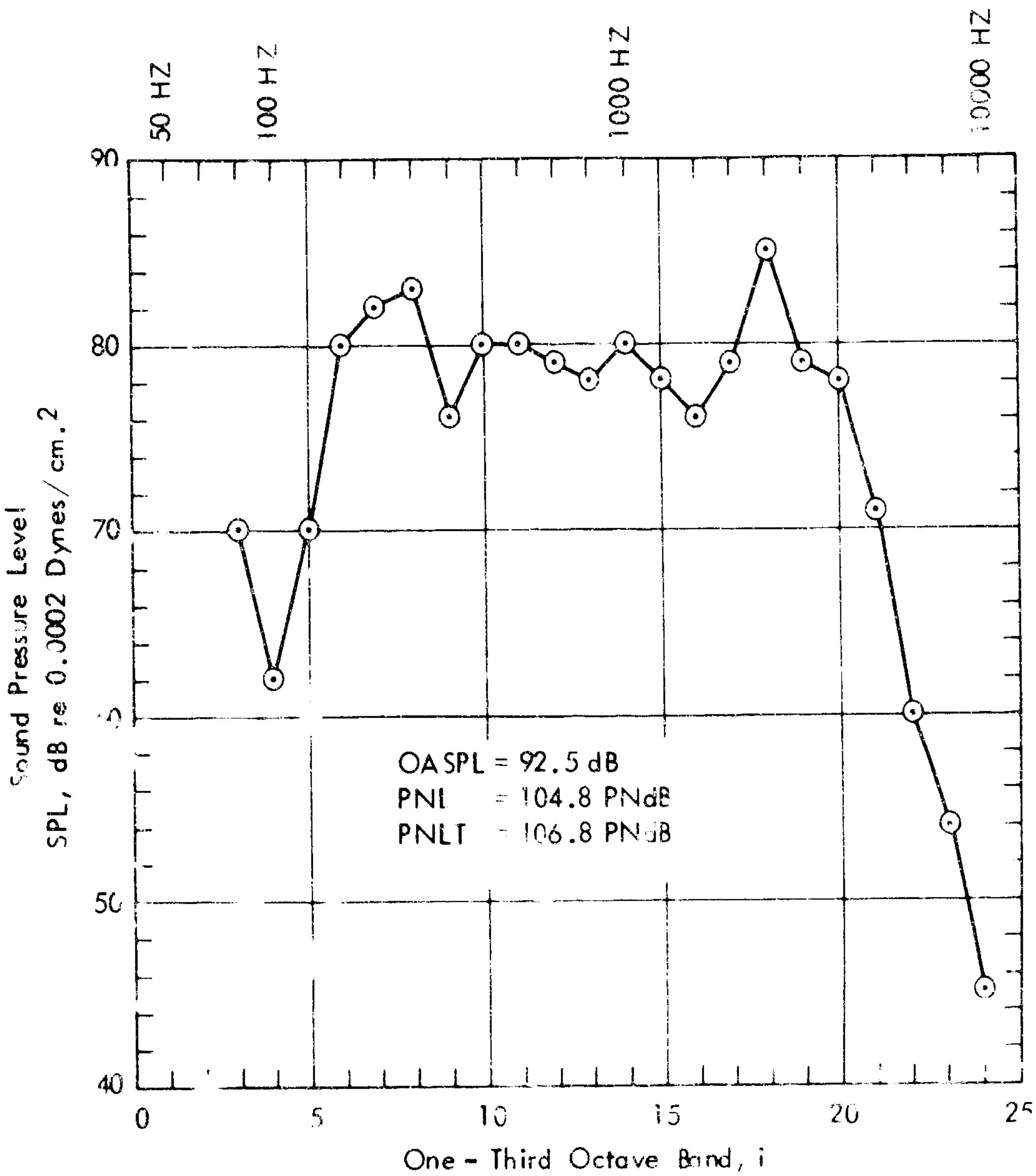

Figure B1. Example of Sound Pressure Level Spectrum
(a) Turbofan Engine

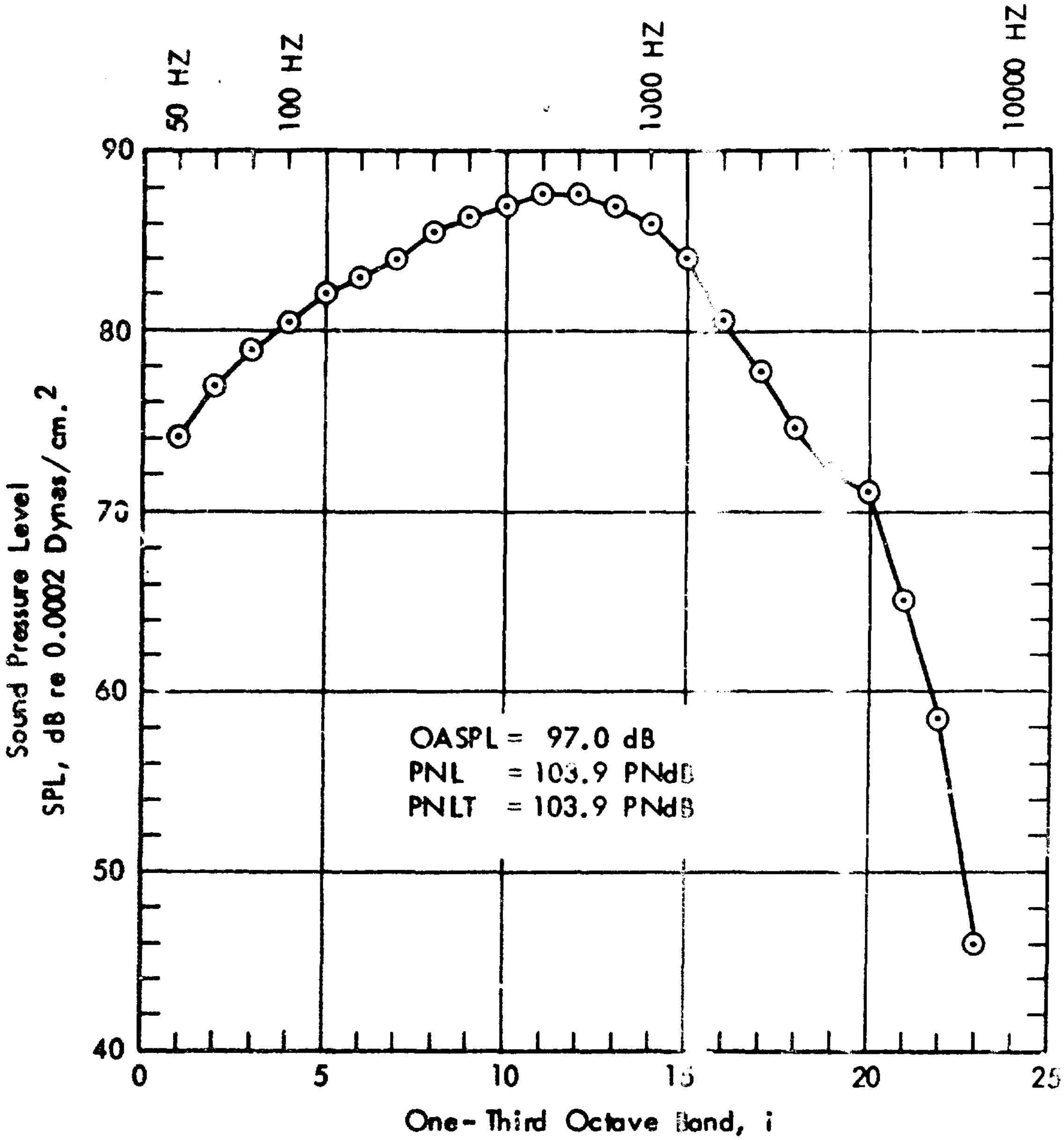

Figure B1. Example of Sound Pressure Level Spectrum
(b) Turbojet Engine

APPENDIX C. EXAMPLES OF TONE CORRECTION CALCULATIONS

Calculations for adjusting noise spectra for the presence of tones are illustrated in Tables C1(a) and (b). The particular spectra used as examples are the two presented in Appendix B for turbofan and turbojet engines, and the calculation procedure is that prescribed in detail in Section 9.

The adjusted spectra in terms of background sound pressure level, SPL", are shown in Figure C1. Comparing the original and adjusted spectra of the turbofan engine, Figures B1(a) and C1(a), it is seen that the irregularities are not so pronounced after the tone correction procedure was exercised. The computed correction is 2 PNdB which, when added to the PNL, resulted in the PNLT value of 106.8 PNdB indicated in Figure B1(a).

Comparing the original and adjusted spectra of the turbojet engine, Figures B1(b) and C1(b), it is seen that only a very slight difference exists. The computed correction is zero which is the reason why the values of PNL and PNLT are identical as indicated in Figure B1(b).

1	2	3	4	5	6	7	8	9	10	11
Band (i)	f HZ	SPL dB	S dB Step 1	|ΔS| dB Step 2	SPL' dB Step 4	S' dB Step 5	$\bar{S}$ dB Step 6	SPL" dB Step 7	F dB Step 8	C dB Step 9
1	50	-	-	-	-	-	-	-	-	-
2	63	-	-	-	-	-	-	-	-	-
3	80	70	-	-	70	-8	-2 1/3	70	-	
4	100	62	- 8	-	62	-8	+3 1/3	67 2/3	-	
5	125	70	+8	16	71	+9	+6 2/3	71	-	
6	160	80	+10	2	80	+9	+2 2/3	77 2/3	2 1/3	
7	200	82	+2	8	82	+2	-1 1/3	80 1/3	1 2/3	
8	250	83	+ 1	1	79	-3	-1 1/3	79	4	2/3
9	315	76	-7	8	76	-3	+ 1/3	77 2/3	-	
10	400	80	+4	11	78	+2	+1	78	2	
11	500	80	0	4	80	+2	0	79	1	
12	630	79	- 1	1	79	-1	0	79	-	
13	800	78	- 1	0	78	-1	- 1/3	79	-	
14	1000	80	+ 2	3	80	+2	- 2/3	78 2/3	1 1/3	
15	1250	78	- 2	4	78	-2	- 1/3	78	-	
16	1600	76	- 2	0	76	-2	+ 1/3	77 2/3	-	
17	2000	79	+ 3	5	79	+3	+1	78	1	
18	2500	85	+ 6	3	79	0	- 1/3	79	6	$\boxed{2}$
19	3150	79	-6	12	79	0	-2 2/3	78 2/3	1/3	
20	4000	78	-	5	78	-1	-6 1/3	76	2	
21	5000	71	-7	6	71	-7	-8	69 2/3	1 1/3	
22	6300	60	-11	4	60	-11	-8 2/3	61 2/3	-	
23	8000	54	- 6	5	54	-6	-8	53	1	0
24	10000	45	- 9	3	45	-9	-	45	-	
						-9				

Step 1	③(i) - ③(i-1)
Step 2	|④(i) - ④(i-1)|
Step 3	see instructions
Step 4	see instructions
Step 5	⑥(i) - ⑥(i-1)

Step 6	[⑦(i) + ⑦(i+1) + ⑦(i+2)] ÷ 3
Step 7	⑨(i-1) + ⑧(i-1)
Step 8	③(i) - ⑨(i)
Step 9	see Table 4.1

Table C1. Example of Tone Correction Calculation
(a) Turbofan Engine

① Band (i)	② f HZ	③ SPL dB	④ S dB Step 1	⑤ |ΔS| dB Step 2	⑥ SPL' dB Step 4	⑦ S' dB Step 5	⑧ $\bar{S}$ dB Step 6	⑨ SPL" dB Step 7	⑩ F dB Step 8	⑪ C dB Step 9
1	50	-	-	-	-	-	-	-	-	-
2	63	-	-	-	-	-	-	-	-	-
3	80	79	-	-	79	+1.5	+1.50	79.00	-	
4	100	80.5	+1.5	-	80.5	+1.5	+1.33	80.50	-	
5	125	82	+1.5	0	82	+1.5	+1.17	81.83	0.17	0
6	160	83	+1	0.5	83	+1	+1.17	83	-	
7	200	84	+1	0	84	+1	+1.17	84.17	-	
8	250	85.5	+1.5	0.5	85.5	+1.5	+1.00	85.34	0.16	
9	315	86.5	+1	0.5	86.5	+1	+0.67	86.34	0.16	
10	400	87	+0.5	0.5	87	+0.5	+0.33	87.01	-	
11	500	87.5	+0.5	0	87.5	+0.5	0	87.34	0.16	
12	630	87.5	0	0.5	87.5	0	-0.50	87.34	0.16	
13	800	87	-0.5	0.5	87	-0.5	-1.17	86.84	0.16	
14	1000	86	-1	0.5	86	-1	-2.17	85.67	0.33	
15	1250	84	-2	1	84	-2	-2.83	83.50	0.50	
16	1600	80.5	-3.5	0.5	80.5	-3.5	-3.17	80.67	-	
17	2000	77.5	-3	0.5	77.5	-3	-2.83	77.50	-	
18	2500	74.5	-3	0	74.5	-3	-2.17	74.67	-	
19	3150	72	-2.5	0.5	72	-2.5	-3.17	72.50	-	
20	4000	71	-1	1.5	71	-1	-4.33	69.33	1.67	0
21	5000	65	-6	5	65	-6	-8.33	65.00	-	
22	6300	58.5	-6.5	0.5	58.5	-6.5	-12.83	56.67	1.83	
23	8000	46	-12.5	6	46	-12.5	-17.17	43.84	2.16	0
24	10000	26.5	-19.5	7	26.5	-19.5	-	26.67	-	
						-19.5				

Step 1	③ (i) - ③ (i-1)
Step 2	|④ (i) - ④ (i-1)|
Step 3	see instructions
Step 4	see instructions
Srep 5	⑥ (i) - ⑥ (i-1)

Step 6	[⑦ (i) + ⑦ (i+1) + ⑦ (i+2)] ÷ 3
Step 7	⑨ (i-1) + ⑧ (i-1)
Step 8	③ (i) - ⑨ (i)
Step 9	see table 4.1

Table C1. Example of Tone Correction Calculation
(b) Turbojet Engine

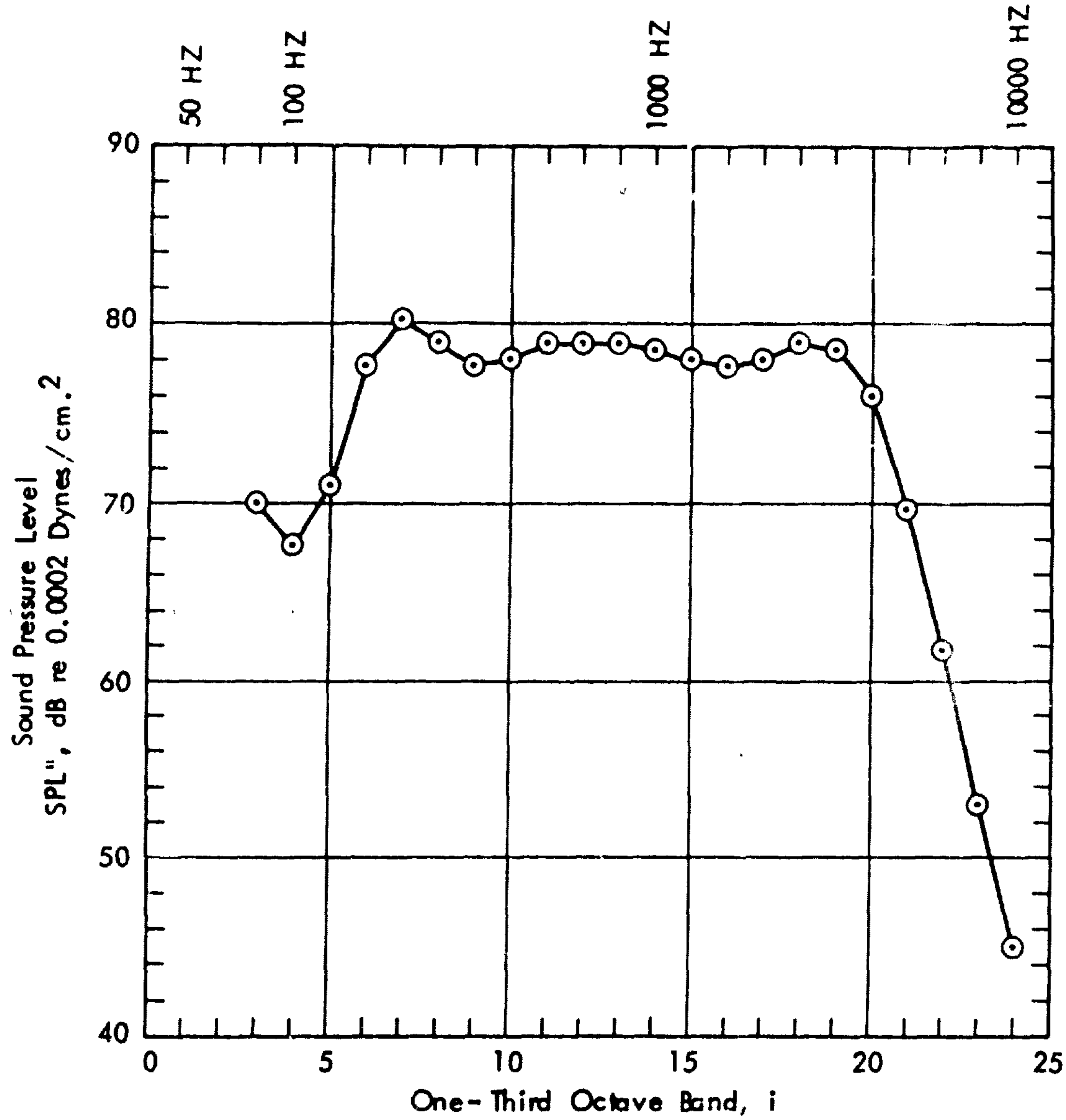

Figure C1. Example of Adjusted Background Sound Pressure Level Spectrum.
(a) Turbofan Engine

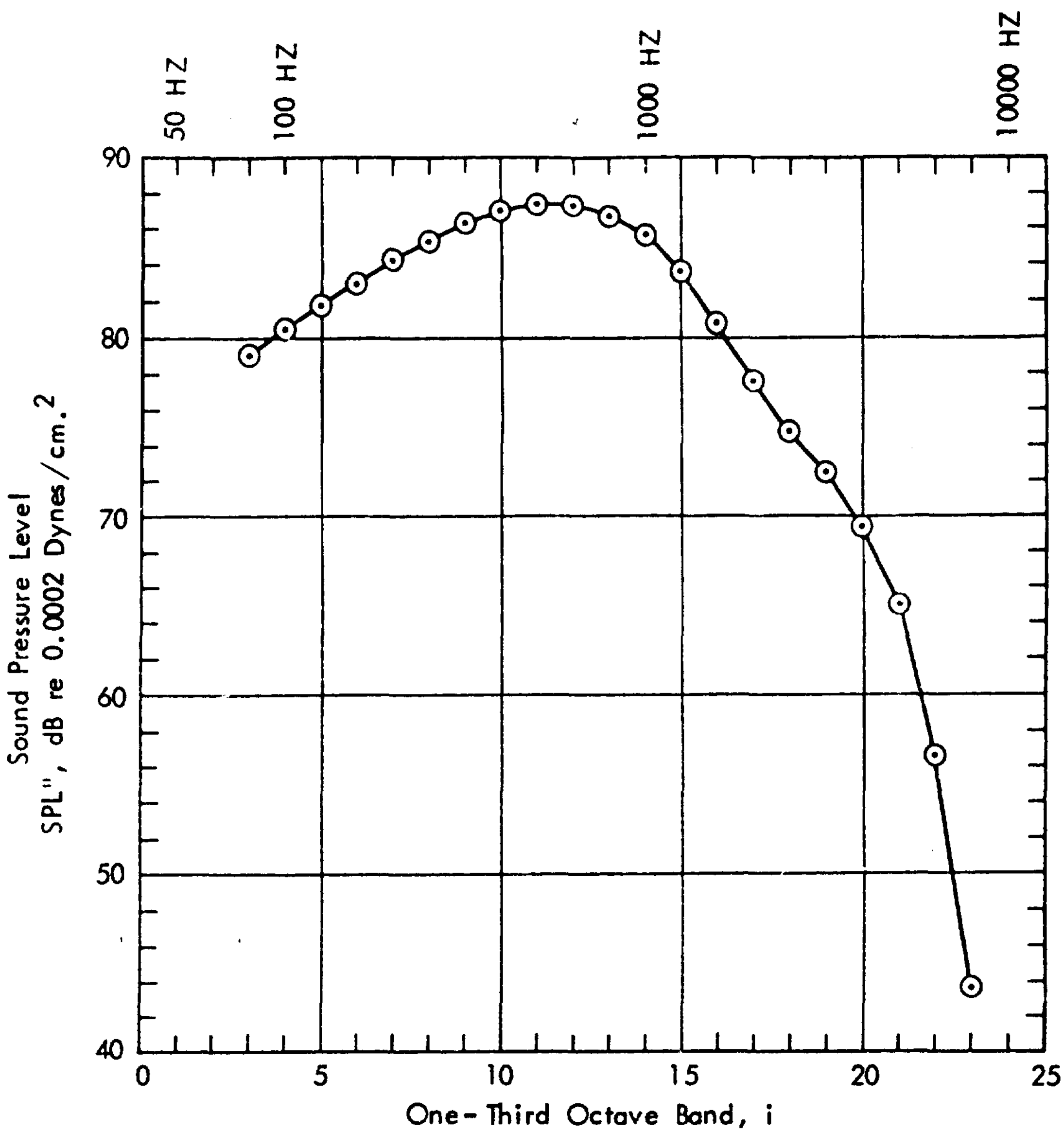

Figure C1. Example of Adjusted Background Sound Pressure Level Spectra
(b) Turbojet Engine

APPENDIX D. EXAMPLES OF DURATION CORRECTION CALCULATIONS

Three examples of flyover curves are shown in Figure D1. These shapes, rectangle, trapazoid, and triangle are not representative of real flyover curves and are used simply as examples for illustrating the calculation procedures of Sections 11 and 12. The ordinates of these Figures are the tone corrected perceived noise level, PNLT, with the maximum value, PNLTM, chosen to be 107 dB in conformance with the value (to the nearest whole number) of the turbofan engine aircraft shown in Figure B1. Thus, the turbofan engine noise spectrum, previously used as an example for the PNL and PNLT computational procedures, is continued as an example for the duration computational procedure. It is assumed to be the spectrum for which PNLT is maximum.

The abscissa of Figure D1 is the flyover time, t, and the values chosen are completely arbitrary. At the 33rd second after the time history has begun, the dB-down point, h, from the maximum is 10-dB which defines the beginning of the significant time history, t(1). The end of the significant time history, t(2), occurs when h is again 10 dB after PNLTM has been passed. Half-second time increments, Δ t, were used in the computational procedures. The duration time, d, for all three cases of Figure D1 is 15 seconds which, in accordance with Equation (12.4), would yield an approximate duration correction, D, of zero. The integrated duration corrections are given in Figure D1 for each case and it is seen that only for the trapazoid case are the approximate and integrated duration corrections equivalent. The results indicate that the integrated duration correction will be greater than the approximate when the flyover curve has a flatter shape than the trapazoid shown and will be less than the approximate when the flyover curve is sharper than the trapazoid.

Figure D2 gives examples of triangular flyover curves with different duration times and in all cases the duration correction, D, is negative. However, the results indicate that D approaches zero as d becomes about 26 seconds.

Figure D3 illustrates three arbitrary noise flyover curves, of which the first two are more representative of reality than those of Figures D1 and D2. The "haystack" examples were chosen to have a 15-second duration time, d, which would yield an approximate duration correction of zero. The integrated duration corrections, however, are dependent upon the curve shape and for the examples shown, are negative. Other flatter curves of 15-second duration could be drawn which would have zero or positive integrated duration corrections.

Figures D4, D5, and D6 illustrate actual takeoff and landing flyover curves for DC-8, DC-9, and B-727 aircraft. Associated with each curve is the calculated integrated duration correction which, in all cases, is negative. The basic data was obtained from Hecker and Kryter, Reference 21.

Table D1 lists all the flyover curves with their duration times and with both integrated and approximate duration corrections. The tabulated results of the

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of the integrated duration corrections are given with respect to three different normalizing times, T. The 10-second normalizing time is that recommended by ISO, Reference 8. The 15-second normalizing time was used by Hecker and Kryter, References 21 and 22, and the 6-second normalizing time is given as a possible future lower limit. The difference in the duration corrections resulting from 6 and 15 instead of 10-second normalizing time is plus or minus 2 dB, respectively.

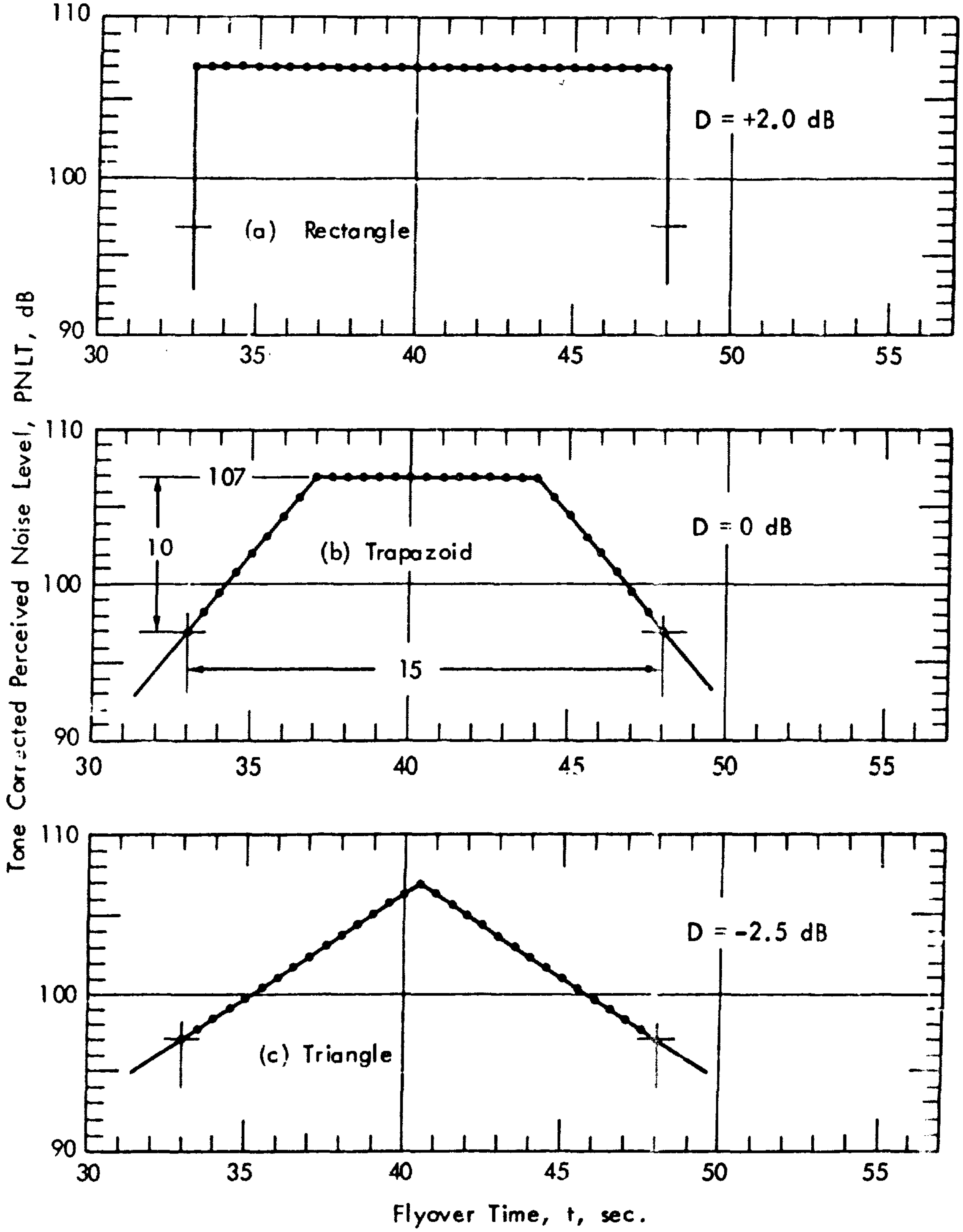

Figure D1. Examples of Miscellaneous Flyover Curves with 15-sec. Duration Times.

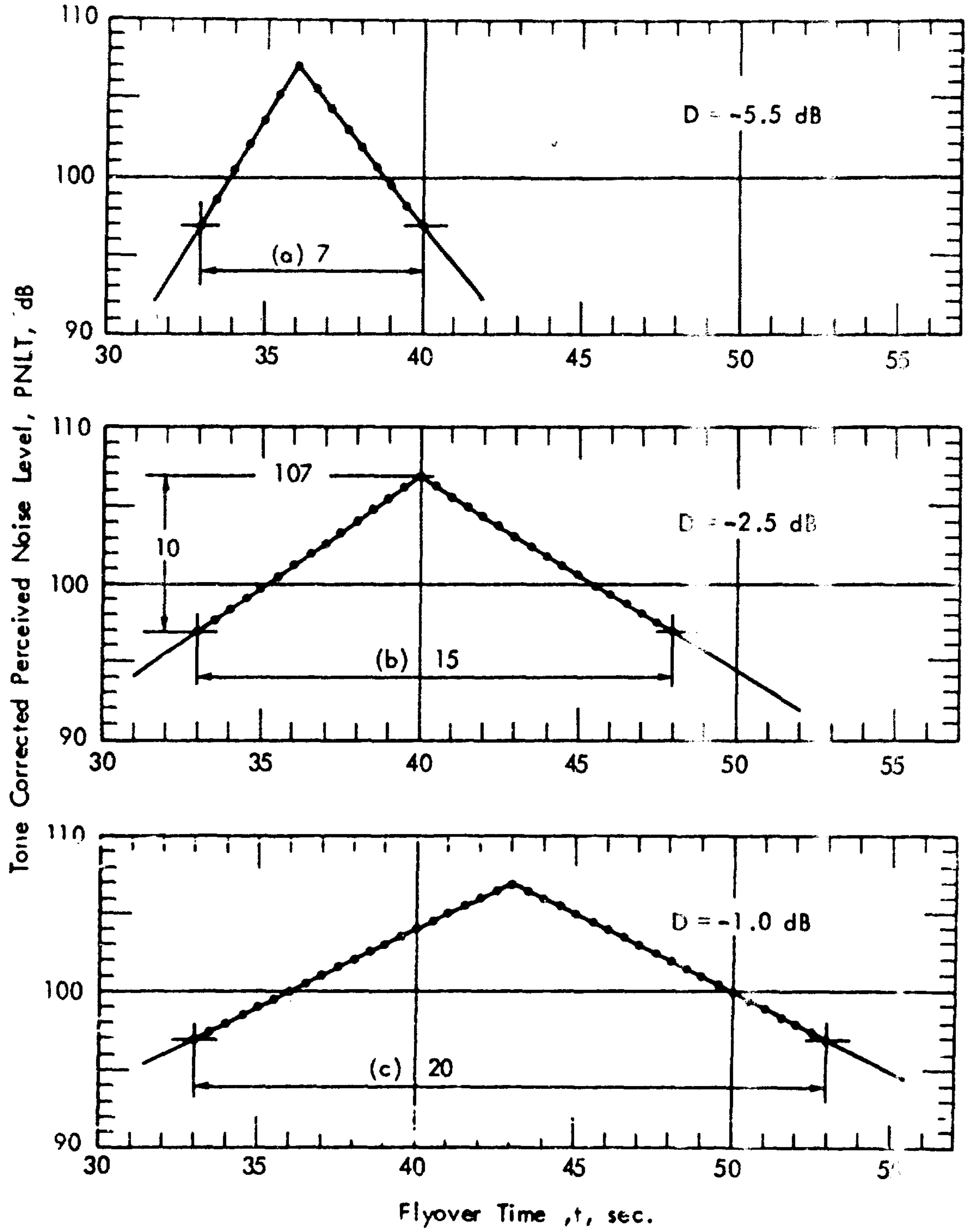

Figure D2. Examples of Triangular Flyover Curves with Different Duration Times

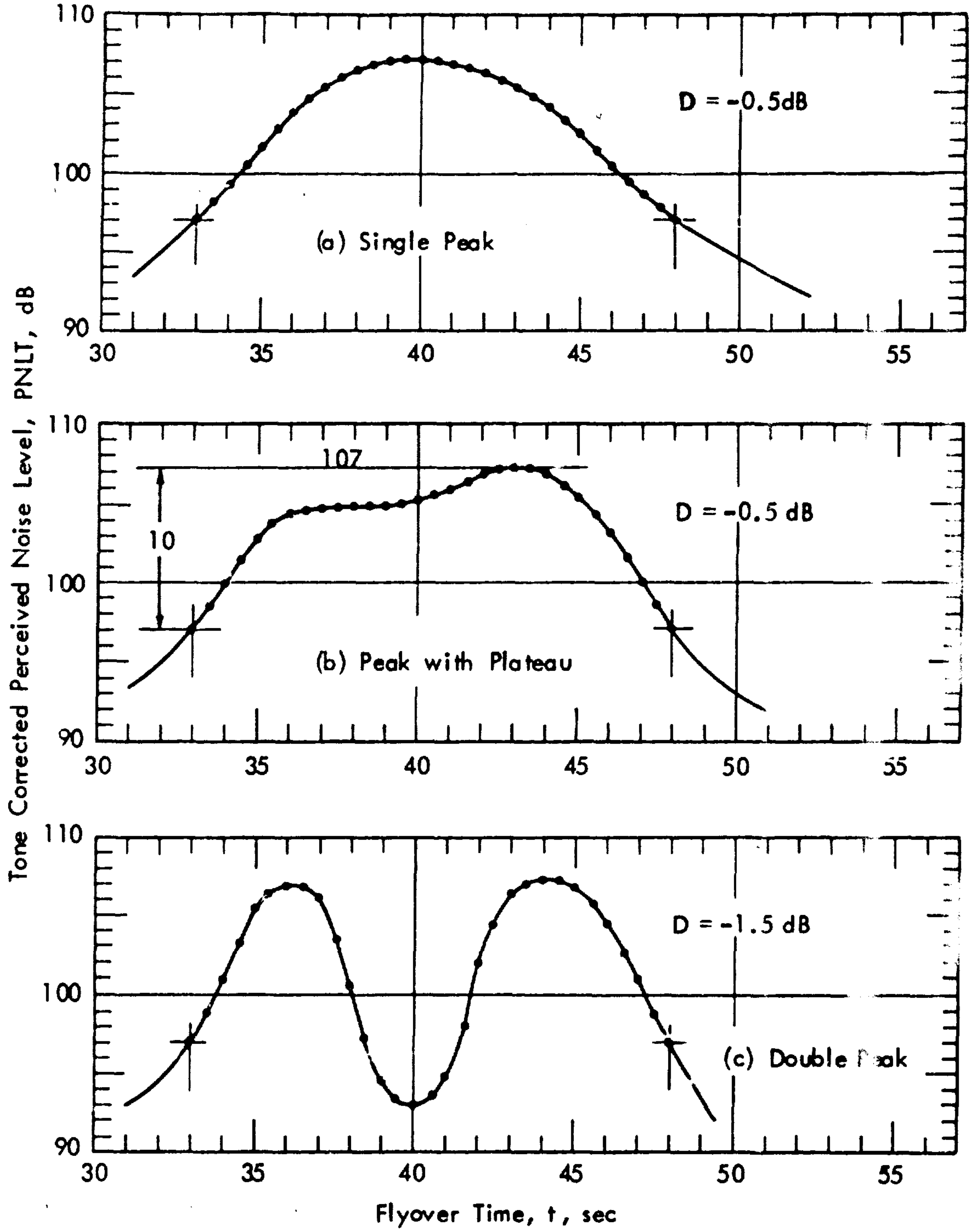

Figure D3. Examples of Haystack Flyover Curves with 15-Sec. Duration Times.

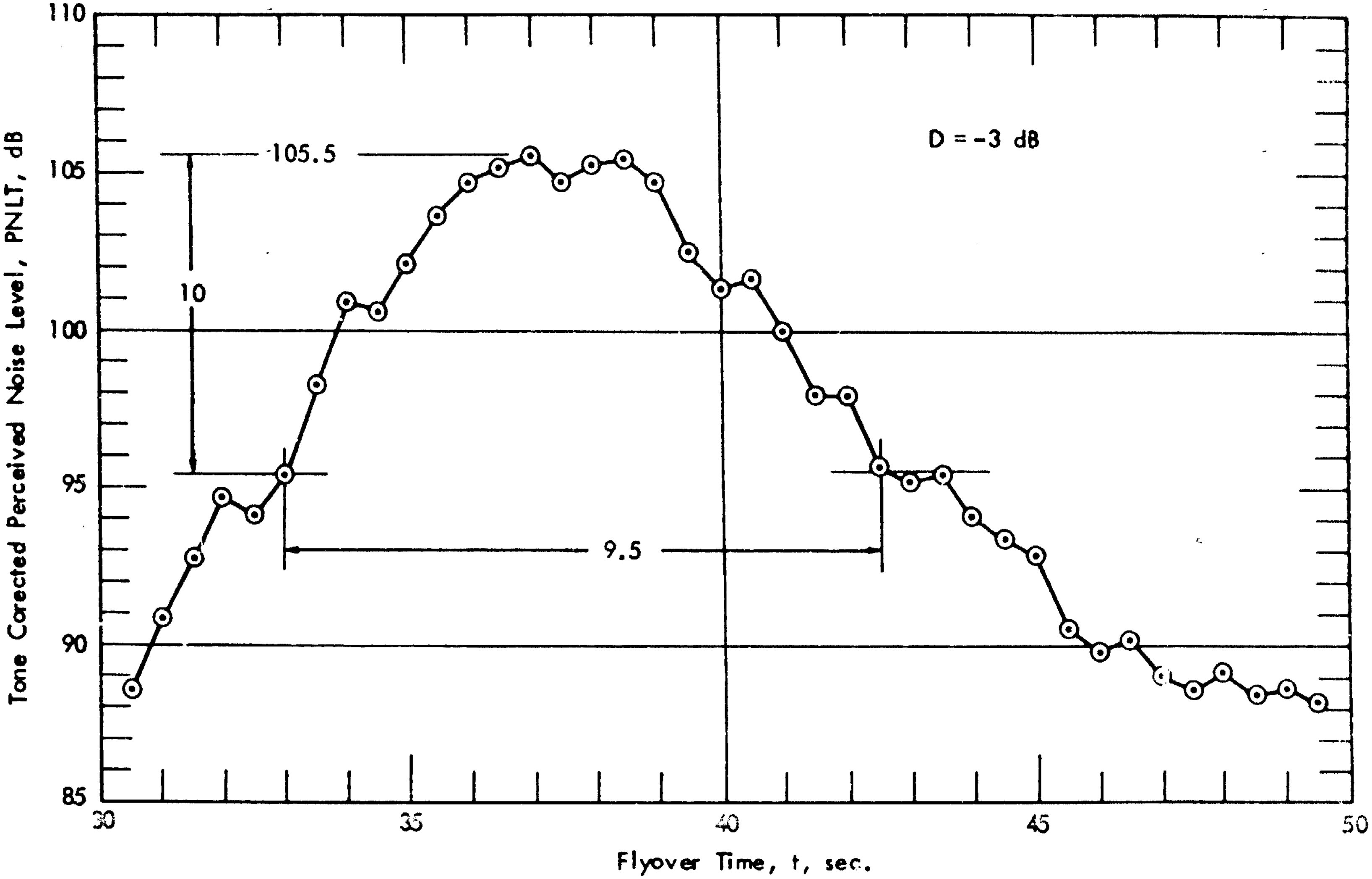

Figure D4. Flyover Curve for DC-8
(a) Takeoff at 980 Ft. Altitude.

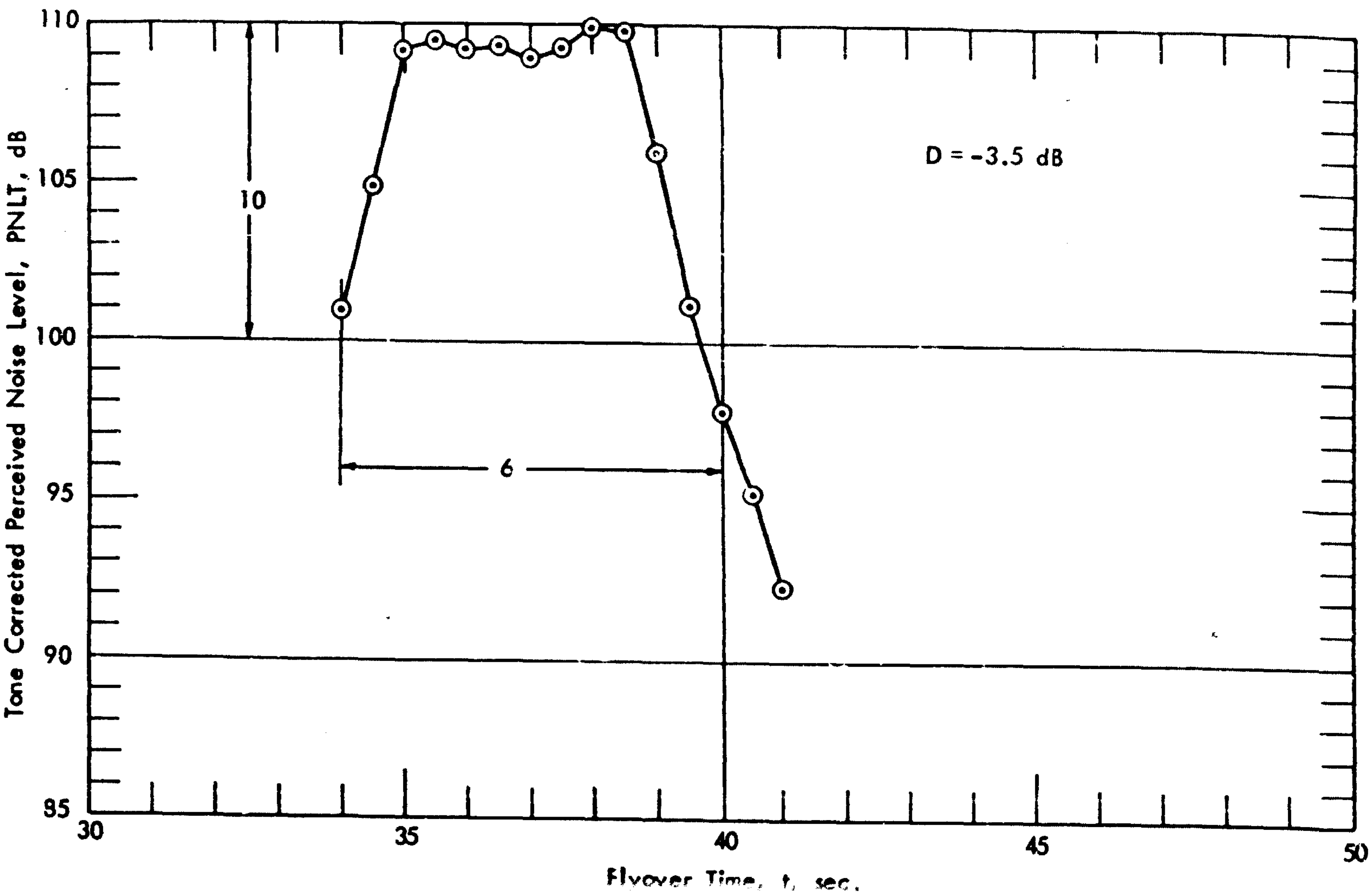

Figure D4. Flyover Curve for DC-8.
(b) Landing at 305 Ft. Altitude.

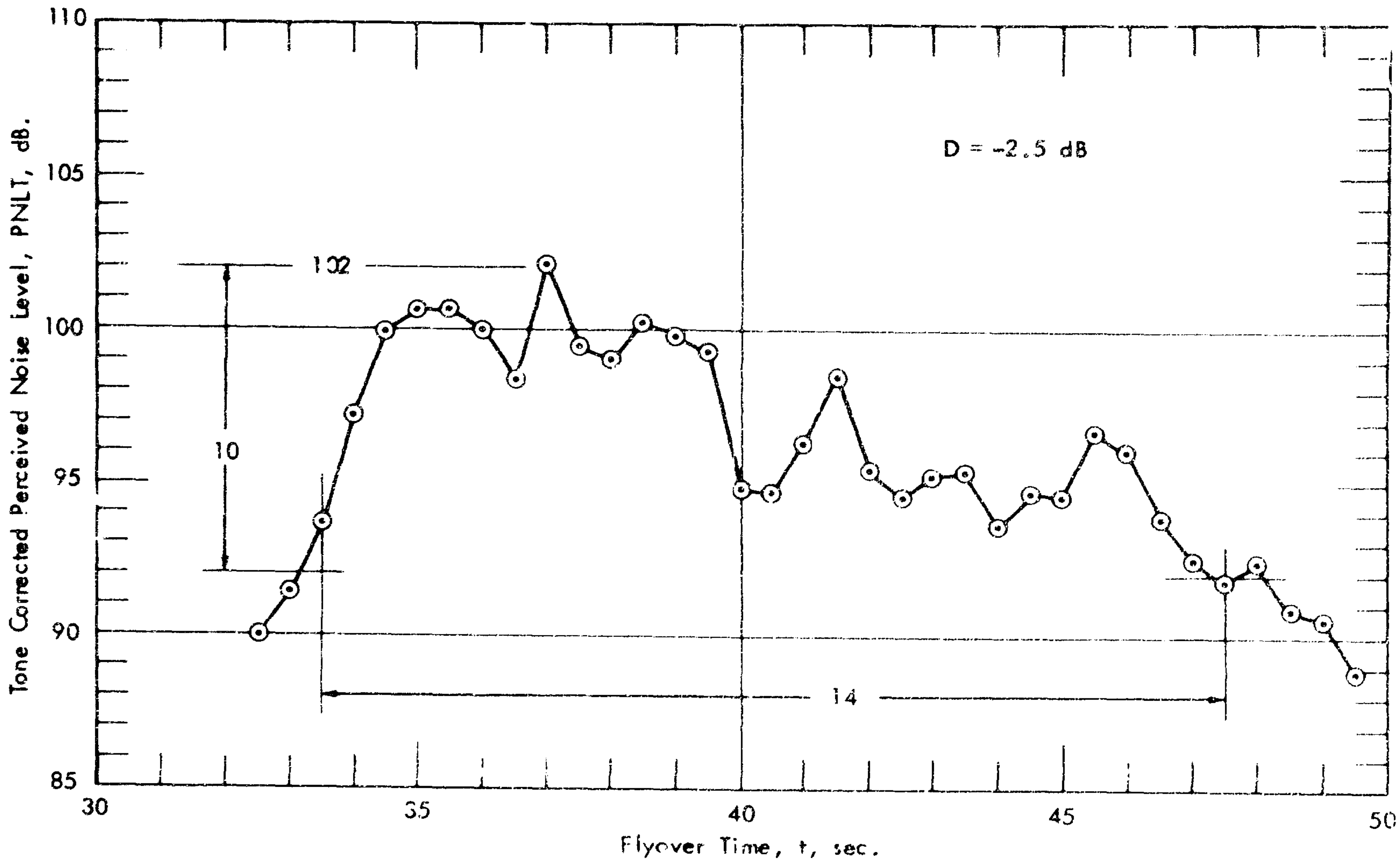

Figure D5. Flyover Curve for DC-9.
(a) Takeoff at 1000 Ft. Altitude.

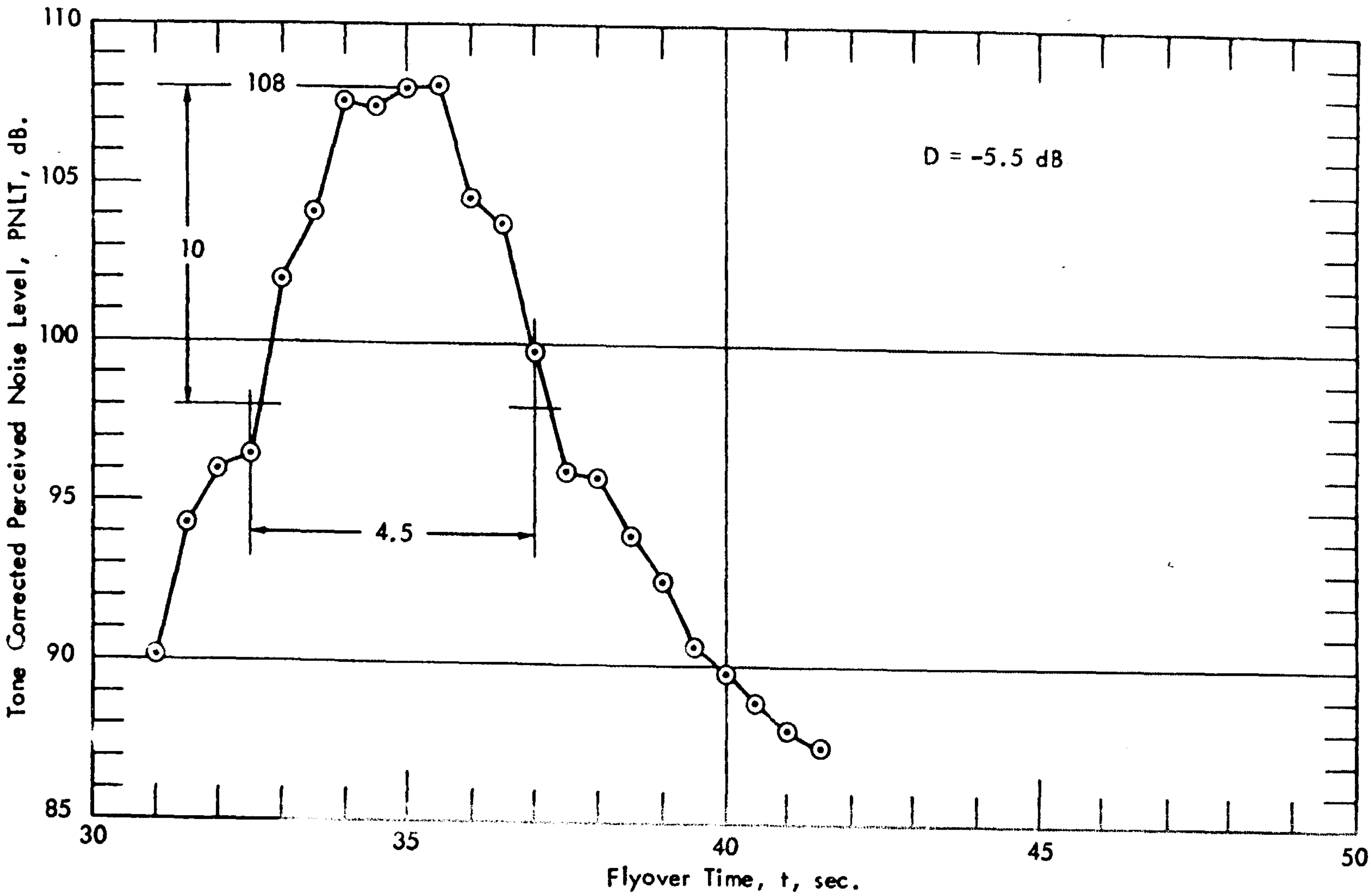

Figure D5. Flyover Curve for DC-9
(b) Landing at 430 Ft. Altitude.

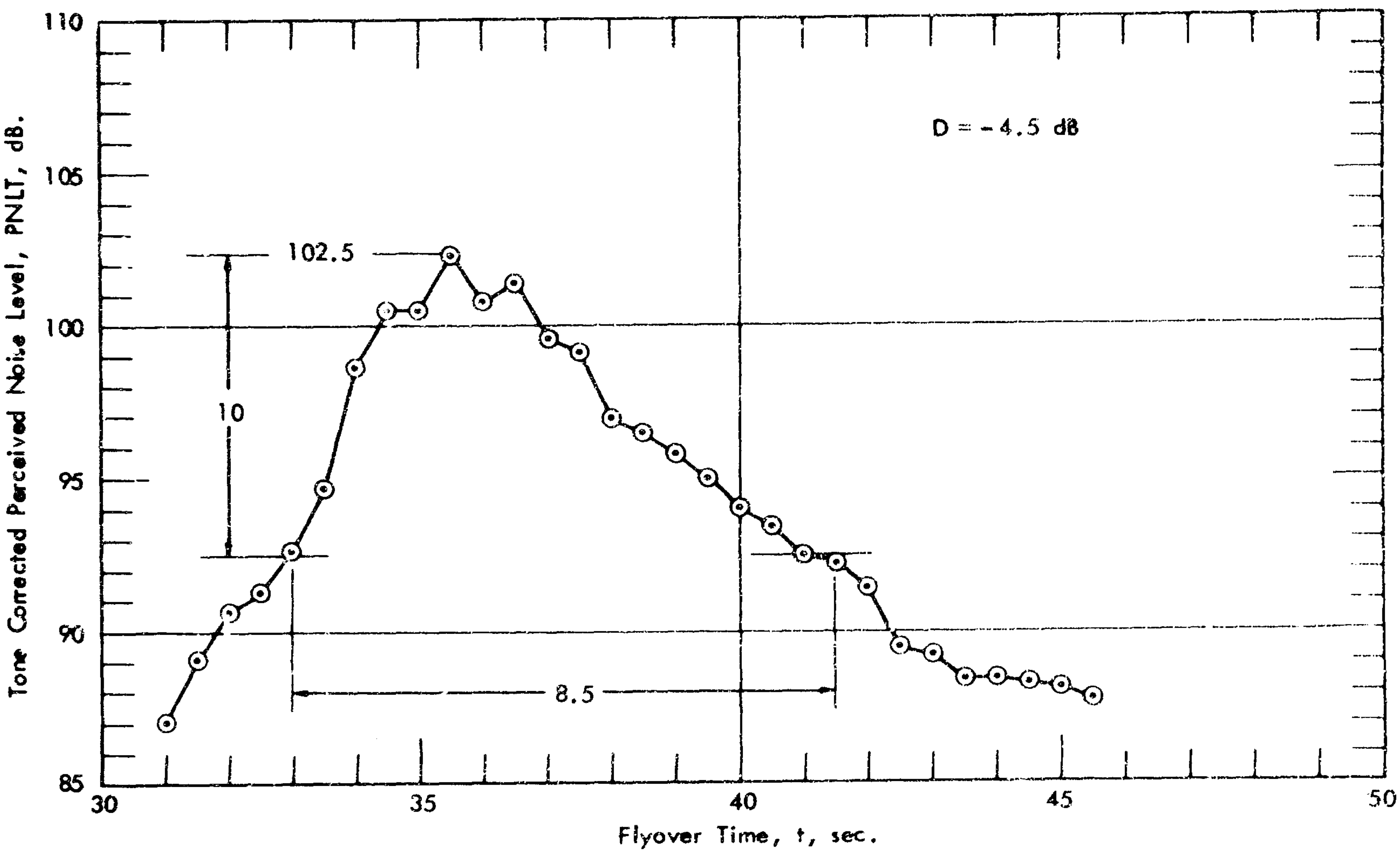

Figure D6. Flyover Curve for 727.
(a) Takeoff at 925 Ft. Altitude.

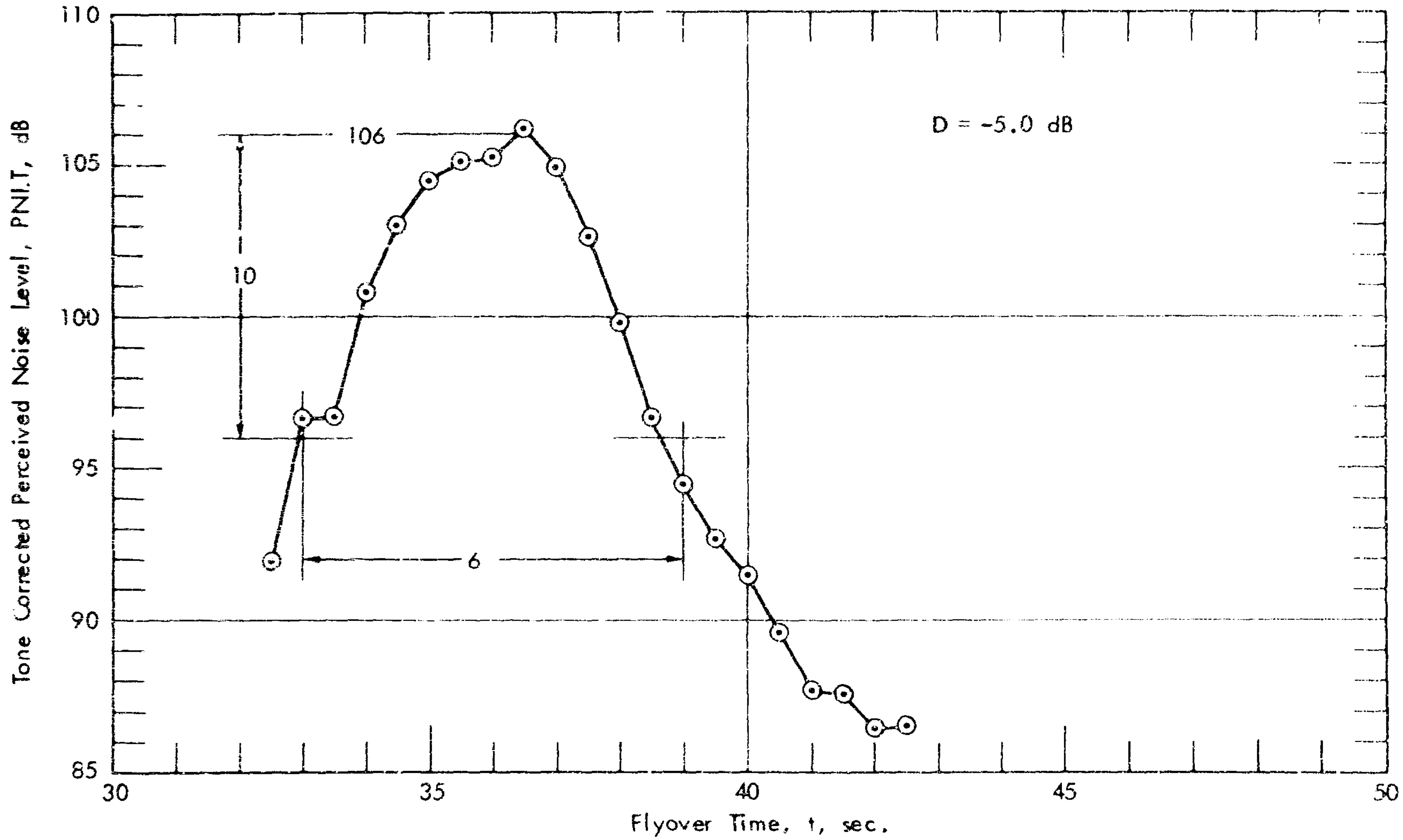

Figure D6. Flyover Curve for 727.
(b) Landing at 358 Ft. Altitude.

Flyover Curve	Dur. Time d sec.	Duration Corr., D, dB			
		Integration Calc.			Approx. Calc.
		Norm. 6	Time, T, sec. 10 (1)	15 (2)	
Rectangle	15.0	+4.0	+2.0	0	0
Trapazoid	15.0	+2.0	0	-2.0	0
Triangle	15.0	+0.5	-2.5	-4.5	0
Triangle	7.0	-3.5	-5.5	-7.5	-3.5
Triangle	15.0	-0.5	-2.5	-4.5	0
Triangle	20.0	+1.0	-1.0	-3.0	+1.5
Single Peak	15.0	+1.5	-0.5	-2.5	0
Peak with Plateau	15.0	+1.5	-0.5	-2.5	0
Double Peak	15.0	+0.5	-1.5	-3.5	0
DC-8 T/O	9.5	-1.0	-3.0	-5.0	-2.0
DC-8 Land.	6.0	-1.5	-3.5	-5.5	-4.0
DC-9 T/O	14.0	-0.5	-2.5	-4.5	-0.5
DC-9 Land.	4.5	-3.5	-5.5	-7.5	-5.0
727 T/O	8.5	-2.5	-4.5	-6.5	-2.5
727 Land.	6.0	-3.0	-5.0	-7.0	-4.0

(1) ISO Recommendation, Ref. 8
(2) Hecker and Kryter, Refs. 21 and 22

Table D1. Comparison of Duration Correction Factors Obtained By Various Calculation Methods.

APPENDIX E. APPROXIMATE METHODS

Various aircraft flyover data are listed in Tables E1 and E2 including the computed results for PNLP, PNLM, and EPNL. The latter is given in Table E2(a) as the result of both the integrated and approximate duration calculation methods and in Table E2(b) as the result of the approximate method only. The data are from the recent research of Hecker and Kryter, References 21 and 22, and the integration and approximation values have been adjusted to conform to normalizing times, T, of 10 and 15 seconds, respectively.

Peak perceived noise level, PNLP, is less sensitive to the physical properties of the noise signature than maximum perceived noise level, PNLM, and both are less sensitive than effective perceived noise level, EPNL. If the prediction of aircraft noise in terms of EPNL is considered to be too complicated, an approximate method would be to first predict the noise in terms of PNLP or PNLM (which the aviation community considers feasible) and then adjust the results to EPNL by some sort of conversion curve. This is precisely what the aviation community has recommended in References 19 and 20, and Figures E1 and E2 show the type of proposed curve where the differences in subjective evaluations are plotted as a function of distance. In all cases shown, the distance represents flyover altitude because the test data was obtained from overhead flights. A more general curve would be in terms of the minimum slant distance which would permit the inclusion of sideline noise measurements.

Figure E1(a) shows the difference between EPNL based upon the integrated duration calculation and PNLM. Superimposed on the graph is the AIA curve from Reference 20. It is apparent that the data has not collapsed very well along any single line and that an envelop should be used to contain the data. The AIA curve might represent the upper boundary of the envelop above 1000 feet altitude but an adjustment would be needed for altitudes below 1000 feet.

Figure E1(b) shows the difference between EPNL based upon the approximate duration calculation and PNLM. For this case, the AIA curve would nearly represent the lower boundary of the envelop. Comparing the two graphs, it is seen that the approximate duration calculation invokes a slight penalty.

Figures E2(a) and (b) show the differences between the two forms of EPNL and PNLP. The AIA curve is not superimposed on these graphs because it is intended to apply to PNLM only. Again, the data scatter is such that an envelop should be used and also the approximate duration calculation is shown to invoke a slight penalty.

Several important conclusions can be drawn from these curves which are based upon measured physical properties of noise signatures of current aircraft.

1. Differences in subjective evaluations versus distance can be adequately represented by envelopes.

2. If the upper boundary of the envelop were used for prediction, EPNL could be conservative (too large) by a maximum of about 6 dB at 200 feet. The conservatism would decrease as the distances became greater amounting to about 3 dB at 1000 feet and 1 dB at 5000 feet

3. Comparing the integration and approximate duration calculation procedures, the former gives EPNL values slightly lower and which can be contained in slightly smaller envelopes.

F/O NO.	AIRCRAFT	ENGINES			OPERATION		
		MODEL	TYPE	NO.	MODE	ALT ft.	DUR sec. (1)
1	DC-8	JT 3D	Fan	4	T/O	980	9.5
2	DC-8	JT 3D	Fan	4	L	305	6.0
3	DC-9	JT 8D	Fan	2	T/O	1000	14.0
4	DC-9	JT 8D	Fan	2	L	430	4.5
5	727	JT 8D-1	Fan	3	T/O	925	8.5
6	727	JT 8D-1	Fan	3	L	358	6.0
7	720	JT 3C-7	Jet	4	T/O	1500	13.0
8	720	JT 3C-7	Jet	4	L	420	11.5
9	880	CJ805-3	Jet	4	T/O	1400	8.5
10	880	CJ805-3	Jet	4	L	700	5.0
11	KC-135	C135-A	Jet	4	T/O	2000	21.5
12	KC-135	C135-A	Jet	4	L	800	8.5
13	1049 G		Prop.	4	T/O	1300	7.5

(1) Referred to the 10 dB down points.

Table E1. Aircraft Flyover Characteristics. Data From Hecker and Kryter, Ref. 21.

① F/O NO.	② AIRCRAFT	③ ALT. ft.	④ PNL PEAK dB	⑤ PNL MAX. dB	⑥ INTEGRATION EPNL dB	⑦ INTEGRATION DIFF. ⑥-④ dB	⑧ INTEGRATION DIFF. ⑥-⑤ dB	⑨ APPROXIMATION EPNL dB	⑩ APPROXIMATION DIFF. ⑨-④ dB	⑪ APPROXIMATION DIFF. ⑨-⑤ dB
1	DC-8	980	105.2	103.6	102.6	-2.6	-1.0	103.5	-1.7	-0.1
2	DC-8	305	108.4	106.9	105.9	-2.5	-1.0	105.9	-2.5	-1.0
3	DC-9	1000	102.1	100.3	99.3	-2.8	-1.0	101.8	-0.3	+1.5
4	DC-9	430	107.2	106.7	102.3	-4.9	-4.4	102.9	-4.3	-3.8
5	727	925	101.9	100.7	97.7	-4.2	-3.0	99.9	-2.0	-0.8
6	727	358	105.2	104.4	100.8	-4.4	-3.6	102.2	-3.0	-2.2
7	720	1500	106.4	104.8	104.3	-2.1	-0.5	105.2	-1.2	+0.4
8	720	420	105.7	104.9	104.7	-1.0	-0.2	105.3	-0.4	+0.4
9	880	1400	103.1	101.2	101.6	-1.5	+0.4	102.6	-0.5	+1.4
10	880	700	103.8	102.9	99.3	-4.5	-3.6	101.0	-2.8	-1.9
11	KC-135	2000	99.2	97.3	98.4	-0.8	+1.1	101.2	+2.0	+3.9
12	KC-135	800	101.2	99.4	97.2	-4.0	-2.2	98.2	-3.0	-1.2
13	1049G	1300	98.1	96.6	94.9	-3.2	-1.7	96.3	-1.8	-0.3

Table E2. Objective Evaluations of Aircraft Flyover Noise.
(a) Data From Hecker and Kryter, Ref. 21.

1	2	3	4	5	6	7	8	9	10	11
F/O Mode	AIRCRAFT	ALT. ft.	PNL		INTEGRATION			APPROXIMATION		
			PEAK dB	MAX. dB	EPNL dB	DIFF. 6-4 dB	DIFF. 6-5 dB	EPNL dB	DIFF. 9-4 dB	DIFF. 9-5 dB
T/O	WC-135B	8000	83.0	81.4	85.0	+2.0	+3.6			
T/O	WC-135B	4000	92.8	90.6	94.5	+1.7	+3.9			
T/O	WC-135B	2000	102.8	100.8	101.7	-1.1	+0.9			
T/O	WC-135B	1300	107.4	105.8	105.2	-2.2	-0.6			
T/O	WC-135B	1000	112.9	111.4	108.7	-4.2	-2.7			
T/O	WC-135B	800	116.4	114.9	111.8	-4.6	-3.1			
T/O	WC-135B	500	120.8	119.8	114.4	-6.4	-5.4			
T/O	WC-135B	250	123.0	122.2	115.5	-7.5	-6.7			
Land.	WC-135B	1500	105.8	104.1	102.9	-2.9	-1.2			
Land.	WC-135B	750	114.3	113.1	112.2	-2.1	-0.9			
Land.	WC-135B	250	122.4	121.1	116.6	-5.8	-4.5			
T/O	KC-135	2000	111.1	108.8	104.9	-6.2	-3.9			
Land.	KC-135	800	108.1	106.3	102.3	-5.8	-4.0			

Table E2. Objective Evaluations of Aircraft Flyover Noise.
(b) Data from Kryter, Ref. 22.

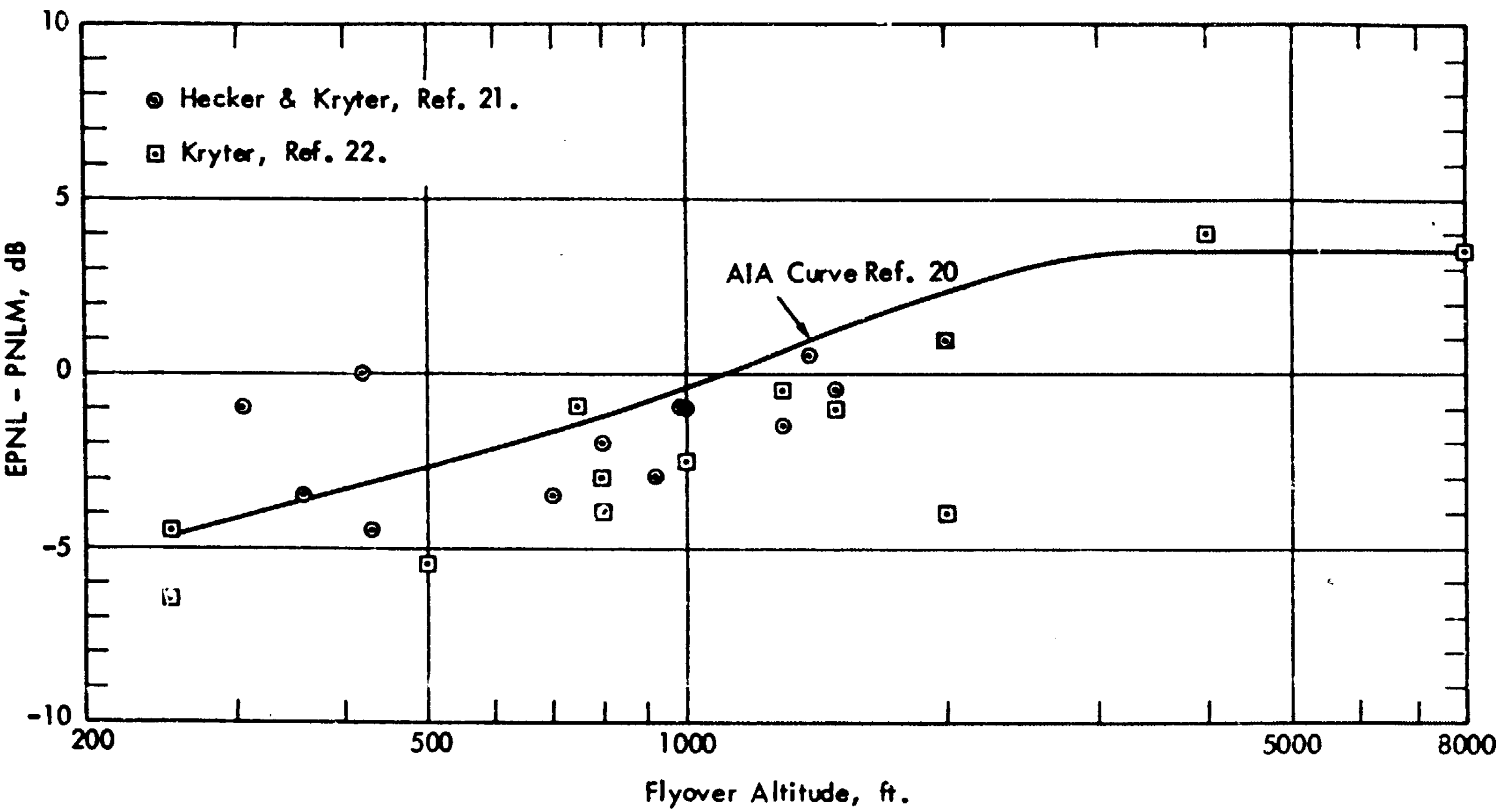

Figure E1. Difference Between EPNL and Max. PNL as a Function of Altitude.
(a) Integrated Duration Calculation.

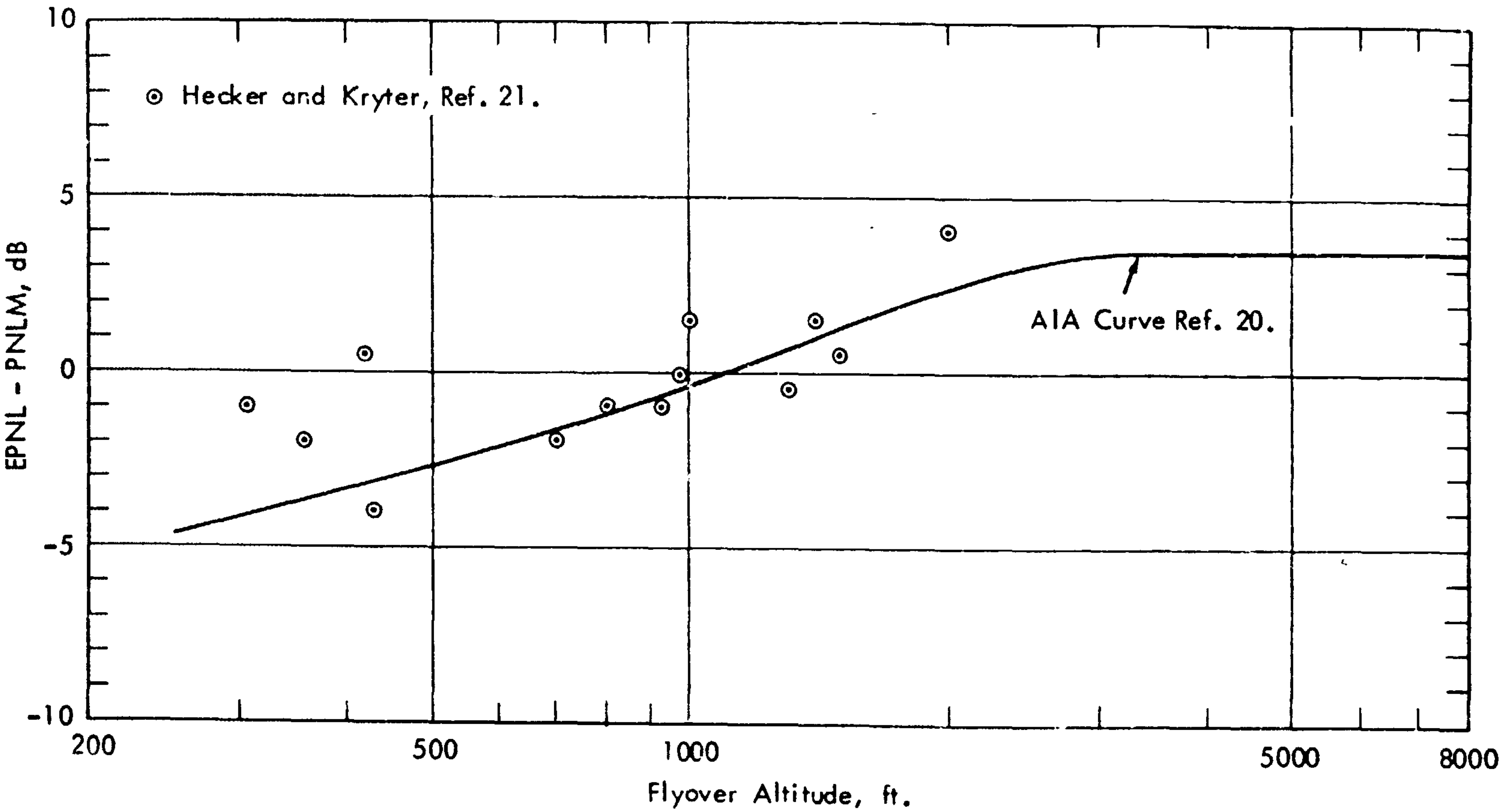

Figure E1. Difference Between EPNL and Max. PNL as a Function of Altitude.
(b) Approximate Duration Calculation.

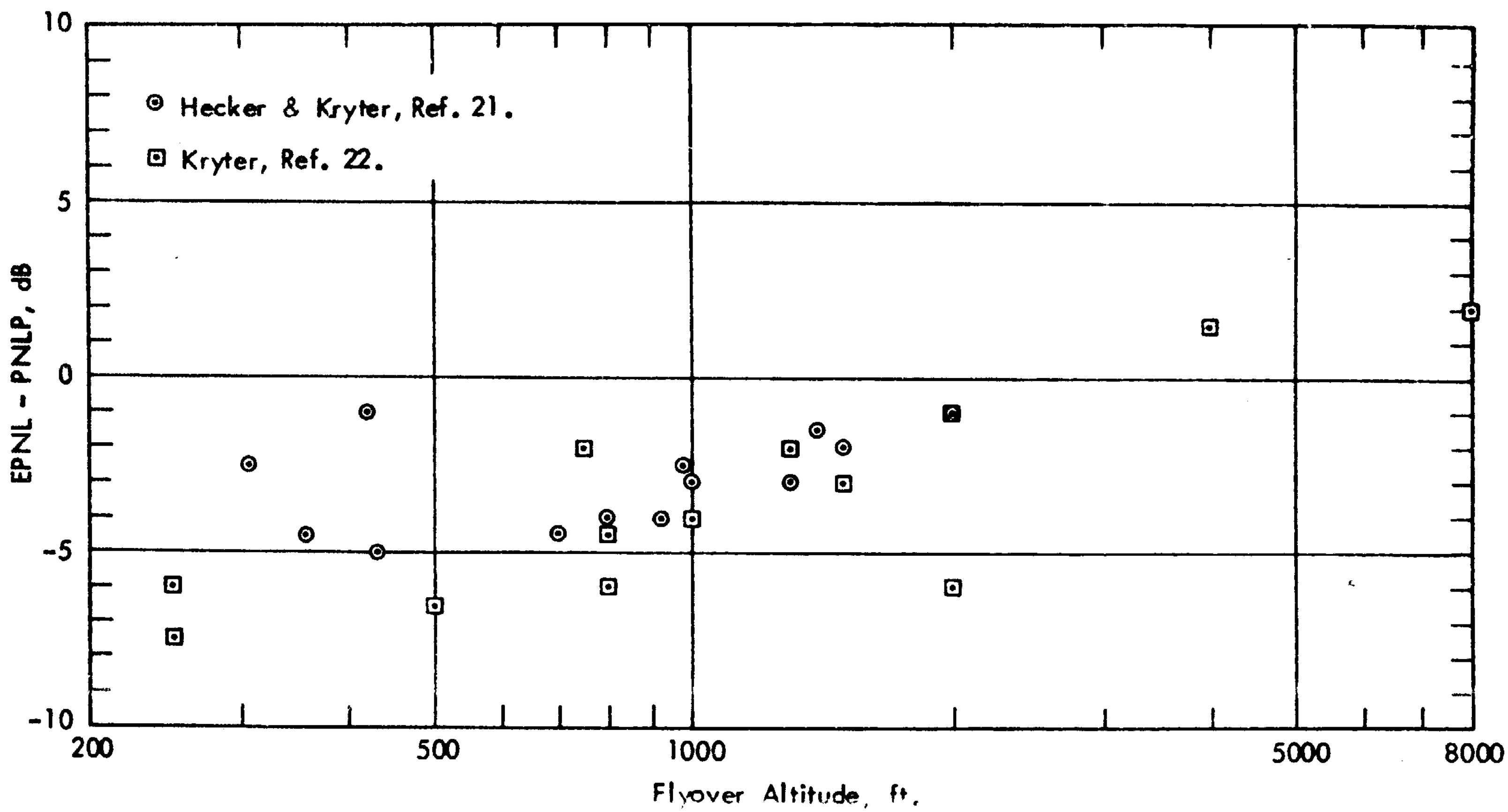

Figure E2. Difference Between EPNL and Peak PNL as a Function of Altitude.
(a) Integrated Duration Calculation

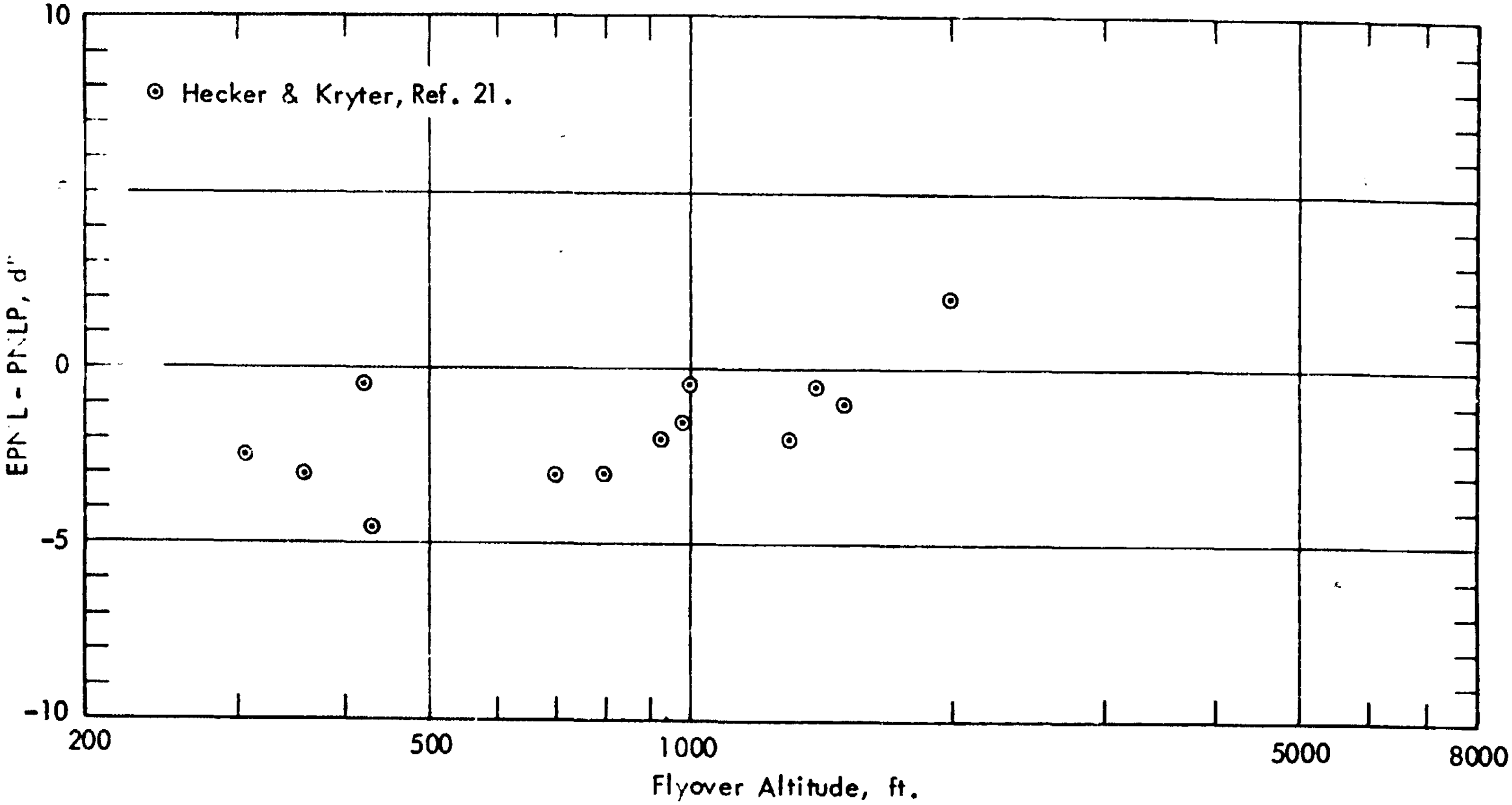

Figure E2. Difference Between EPNL and Peak PNL as a Function of Altitude.
(b) Approximate Duration Calculation.